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AUGUST 1961

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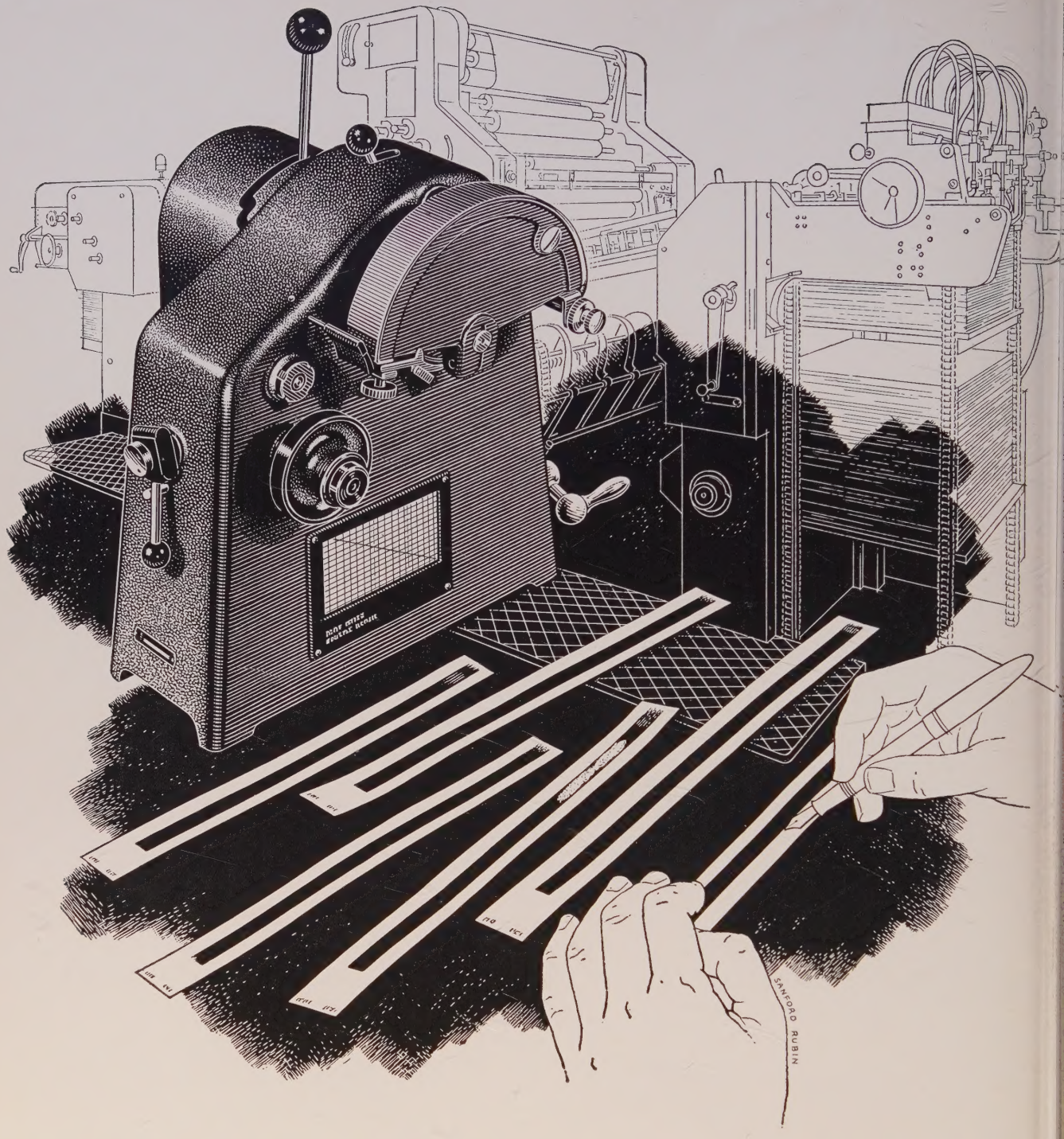

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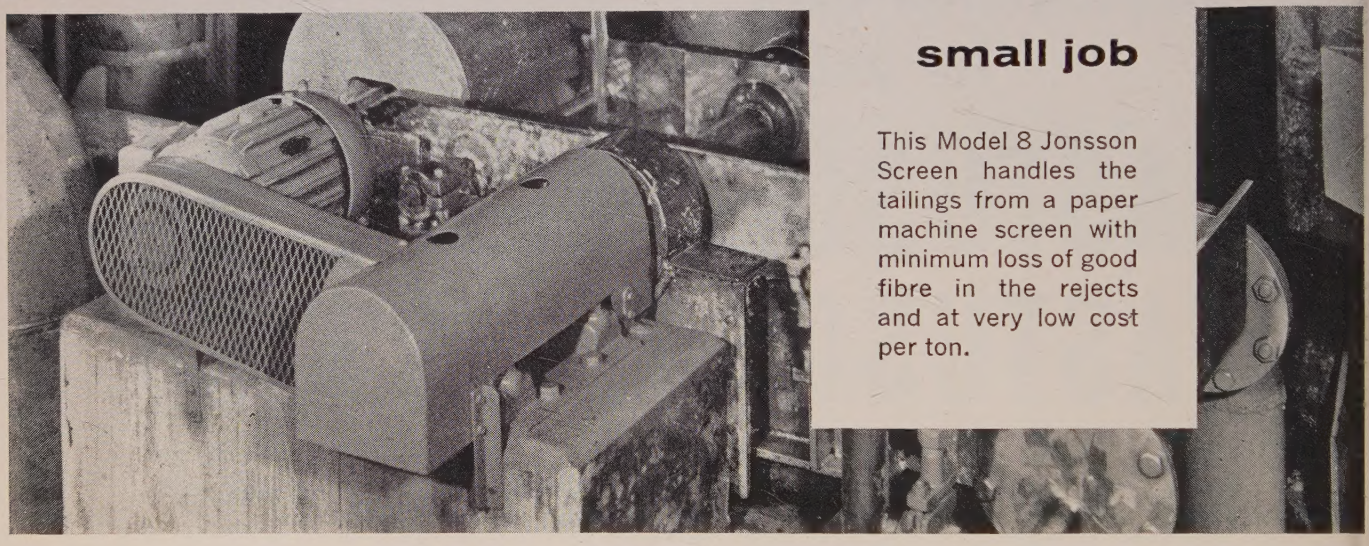

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National Conferences

Eleventh Corrugated Containers Conference
St. Francis Hotel, San Francisco, Calif.
Sept. 6–8, 1961

Fourth International Mechanical Pulping Conference
(Tech. Sect., CPPA-TAPPI)
Edgewater Beach Hotel, Chicago, Ill.
Sept. 19–21, 1961

Sixth Deinking Conference
Hotel Harris, Kalamazoo, Mich.
Oct. 4–6, 1961

Sixteenth Plastics-Paper Conference
French Lick Sheraton Hotel,
French Lick, Ind.
Oct. 9–11, 1961

Sixteenth Engineering Conference
Shoreham Hotel, Washington, D. C.
Oct. 15–19, 1961

Fifteenth Alkaline Pulping Conference
Rice Hotel, Houston, Tex.
Nov. 1–3, 1961

Please refer to Local Section Activities for the locations and dates of Section Meetings

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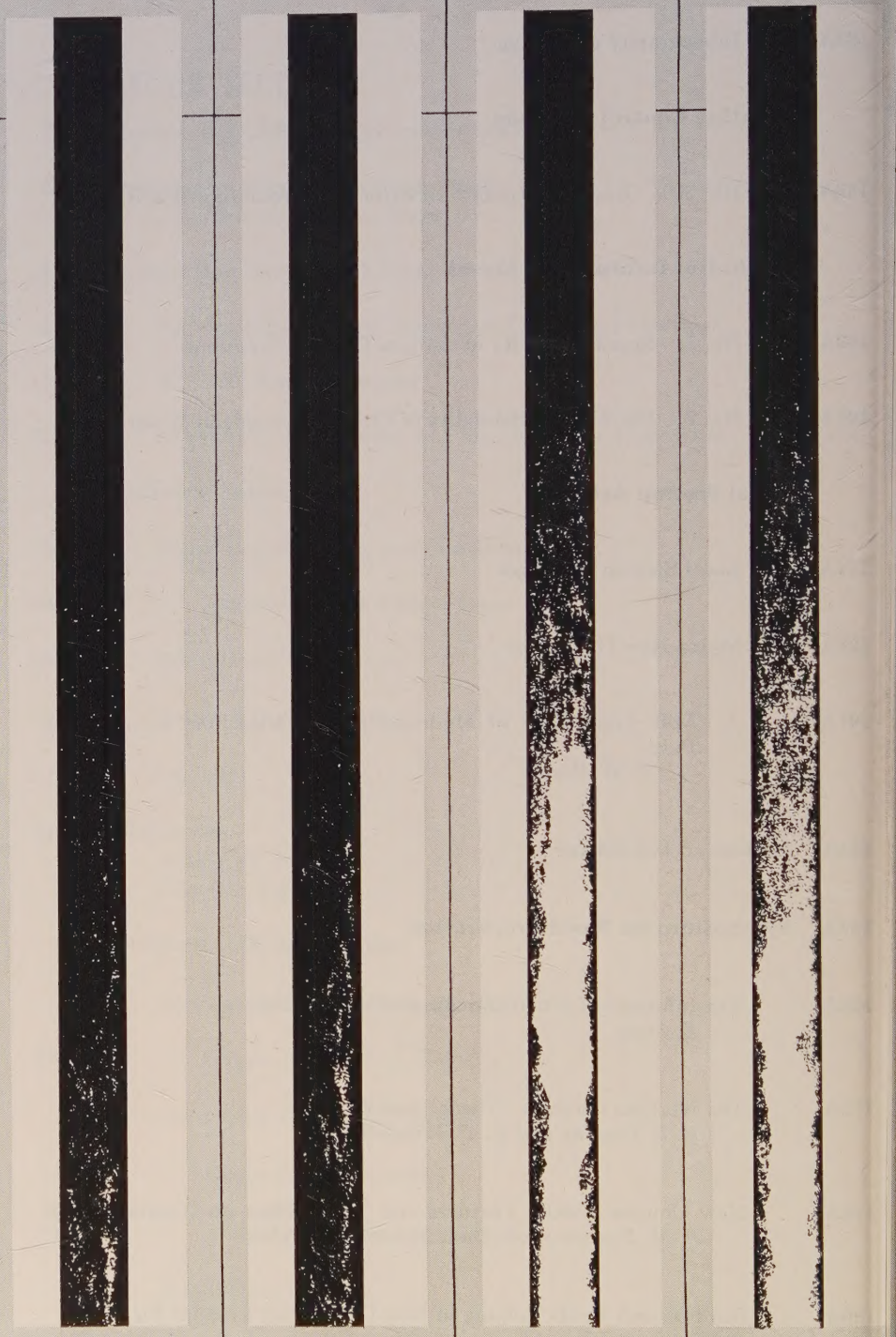
INK USED IPI NO. 6

SPRING TENSION USED [X] A [ ] B

PRINTING VELOCITY, FT./MIN. AT 35 Kg. PRINTING PRESSURE

A TENSION	B TENSION
	100
100	200
200	300
	400
300	
	500
400	
	600



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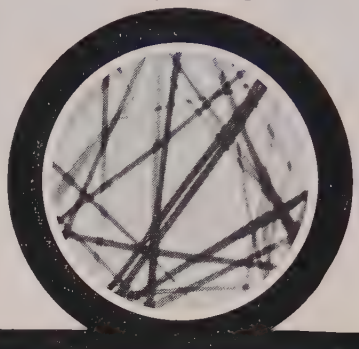
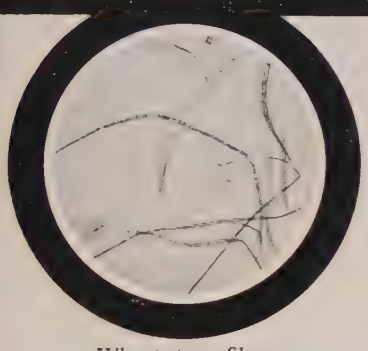
This new integrated pulp and paper mill produces 100 tons per day of high grade bleached and unbleached papers from sugar cane bagasse fiber. Our Organization supplied this project with technical assistance and the major production equipment including a Horkel System for depithing and cleaning the raw bagasse, a Pandia Continuous Digester and the Black-Clawson fourdrinier paper machine shown here.

Completely depithed bagasse fibers



NEW MILLS MAKING PAPER FROM BAGASSE AND STRAW



Wheat straw fibers

EMPAQUES DE CARTON TITAN S.A., MONTERREY, MEXICO

Under a package contract, we supplied principal equipment and start-up assistance for the recent expansion of this mill to produce 60 metric tons per day of unbleached wheat straw pulp for corrugating medium. Straw processing and pulping in a Pandia Continuous Digester is accomplished in this compact, semi-enclosed installation.

These Latin American projects are but two of the 25 pulp and paper mills throughout the world for which the Parsons & Whittemore-Lyddon Organization has provided full or partial planning, technical, economic, and construction services. Twelve different papermaking fibers are utilized among these projects. We even supervise start-up and train local operating personnel, and can arrange for sale of the output on world markets. For literature and full information on how our services can benefit your mill projects, write our nearest office.

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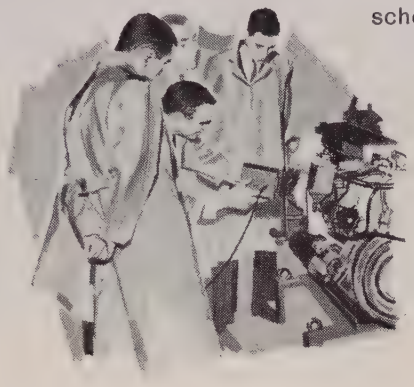

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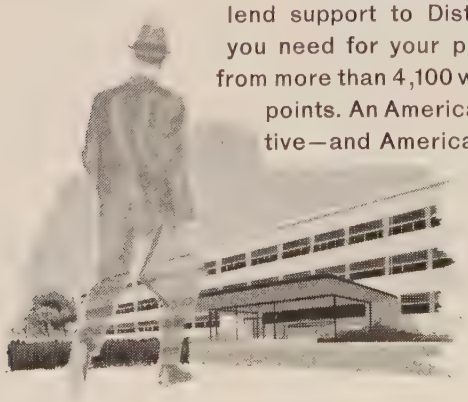

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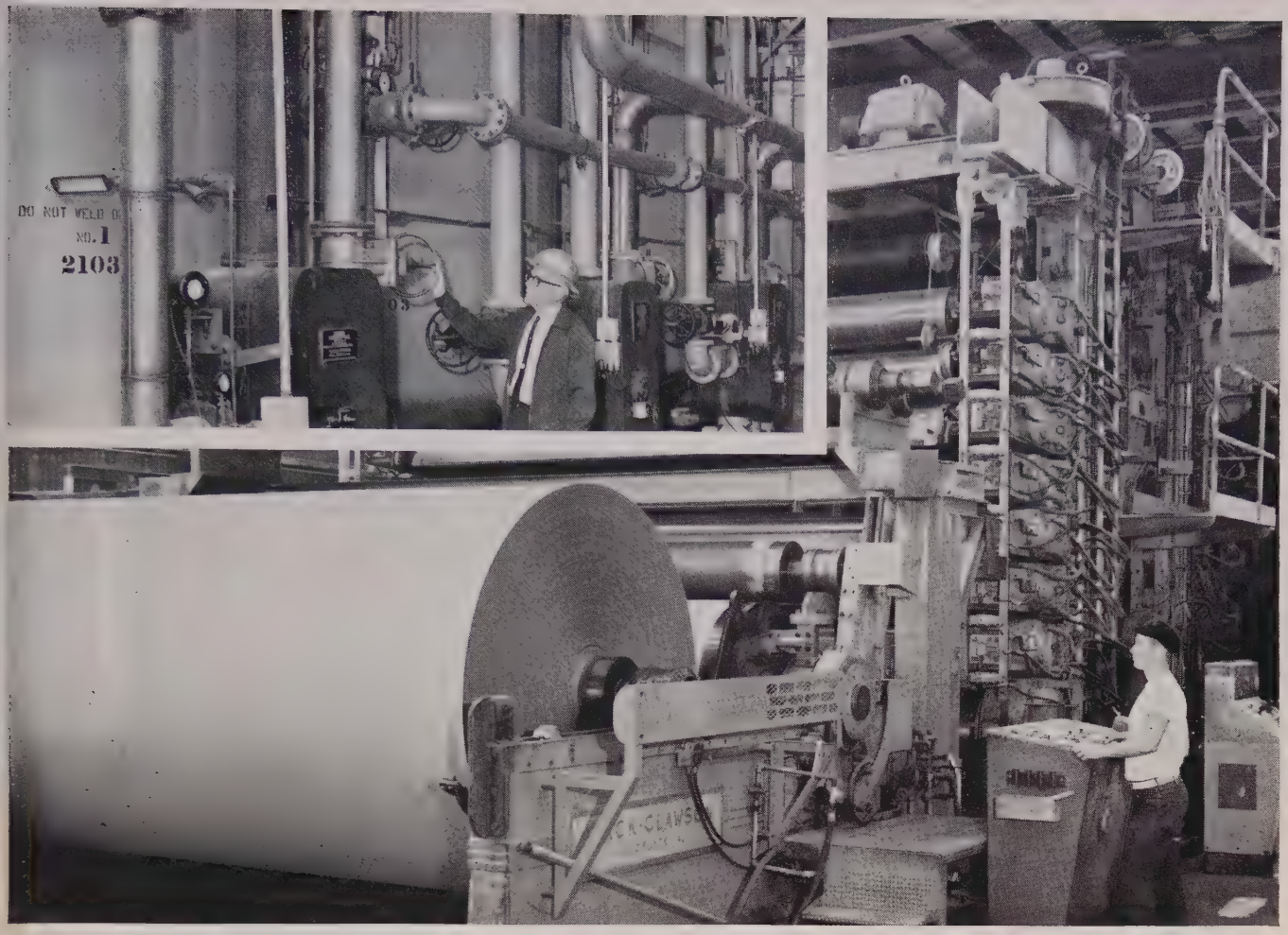

INSET: Ion exchange units at Longview Fibre Company, Longview, Washington. Three 2-bed systems operate in parallel.

AMBERLITE® ion exchange resins still effective at Longview Fibre after treating 2,000,000,000 gallons of river water

Deionizing boiler makeup water for power generation at Longview Fibre Company, Longview, Washington, makes heavy demands on ion exchange resins. Raw water from Columbia River has high silica content (as much as 19 ppm SiO_2) and contains some organic material. Clarification requires heating, and water enters ion exchange beds at an elevated temperature of 95°-100°F.

Serving under these conditions, AMBERLITE IR-120 cation exchange resin and AMBERLITE IRA-400 anion exchanger operating in three 2-bed units have treated a combined grand total of over two billion gallons of water to date. Each cubic foot of anion exchange resin in two of these 2-bed units, installed in 1954, has treated over 4,300,000 gallons of water. (Third unit was installed in 1957.) Treated water has 750,000 ohms specific resistivity and only 0.03-0.05 ppm silica content.

The service AMBERLITE resins provide for Longview Fibre is typical of AMBERLITE performance in uses ranging from boiler water treatment to chemical processing. A broad selection of Rohm & Haas ion exchange resins lets you pick the right resin for any application. Write for technical literature and information.

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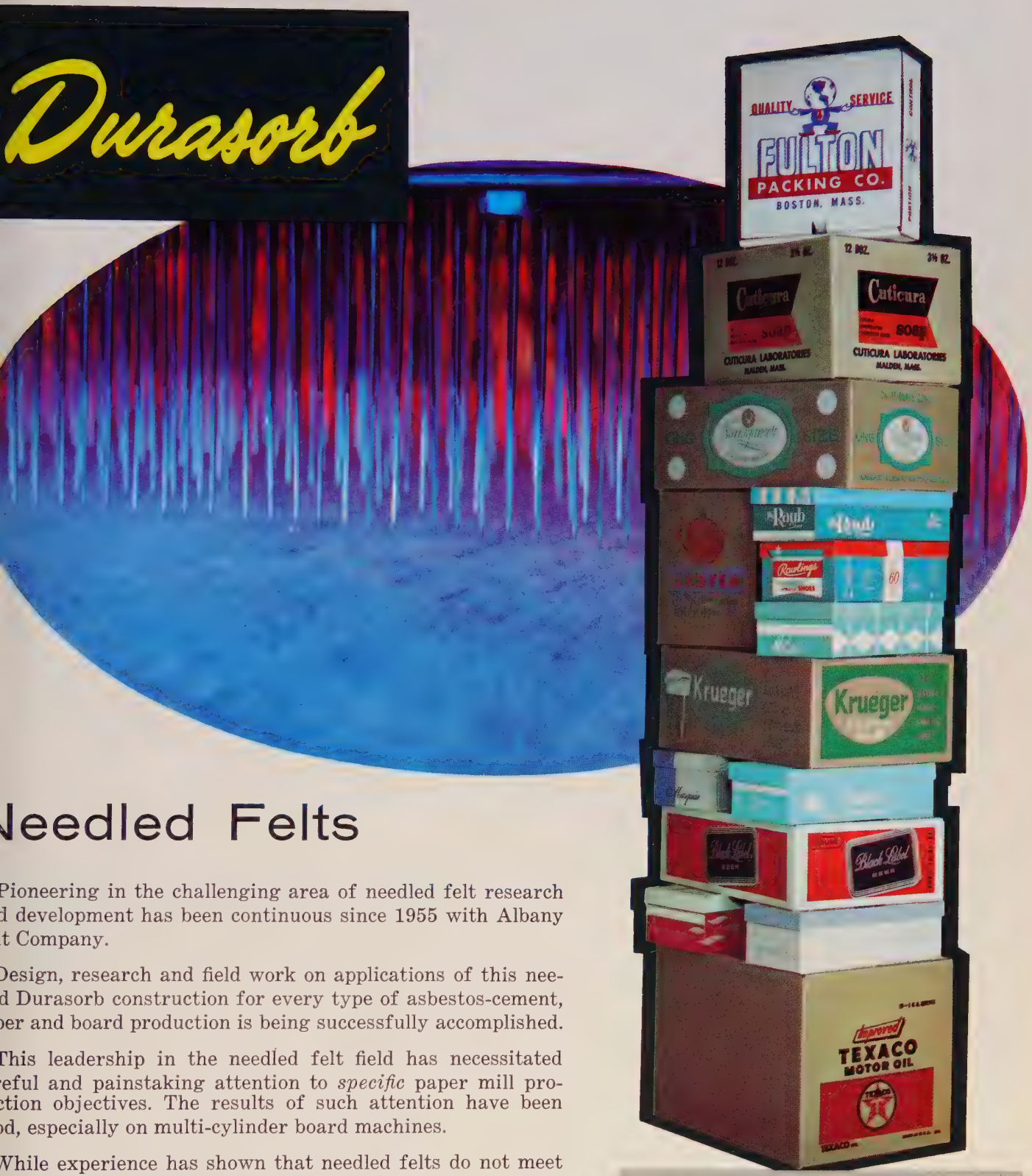

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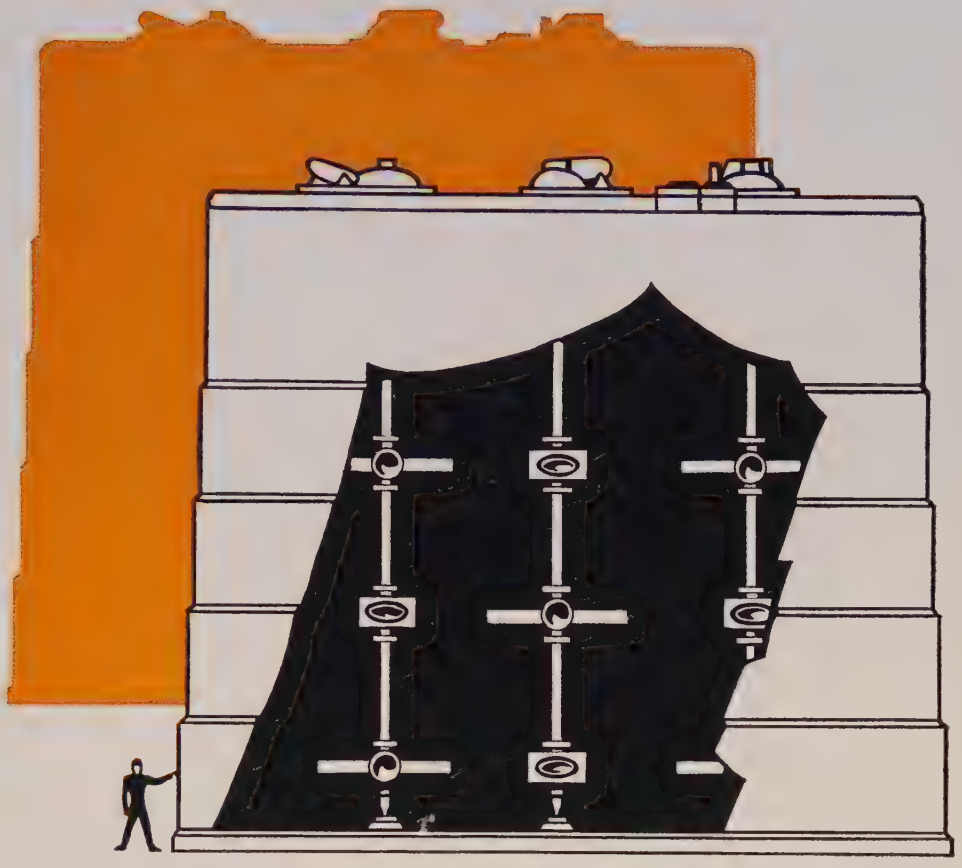

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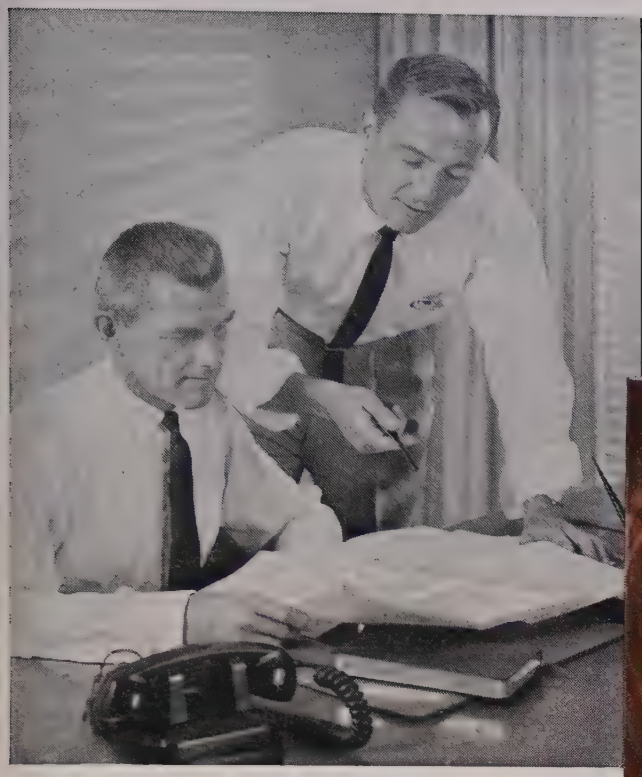

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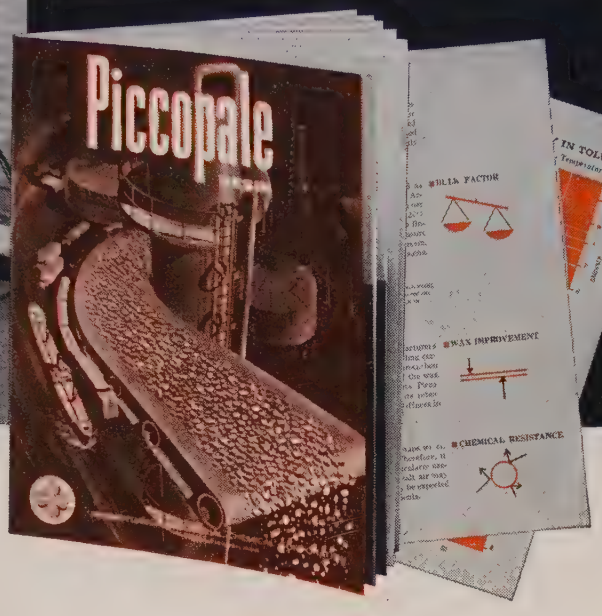

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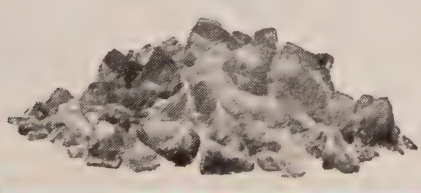

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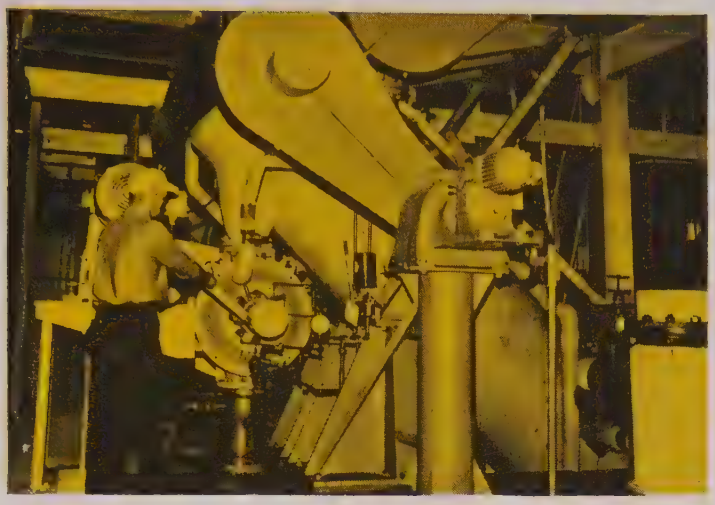

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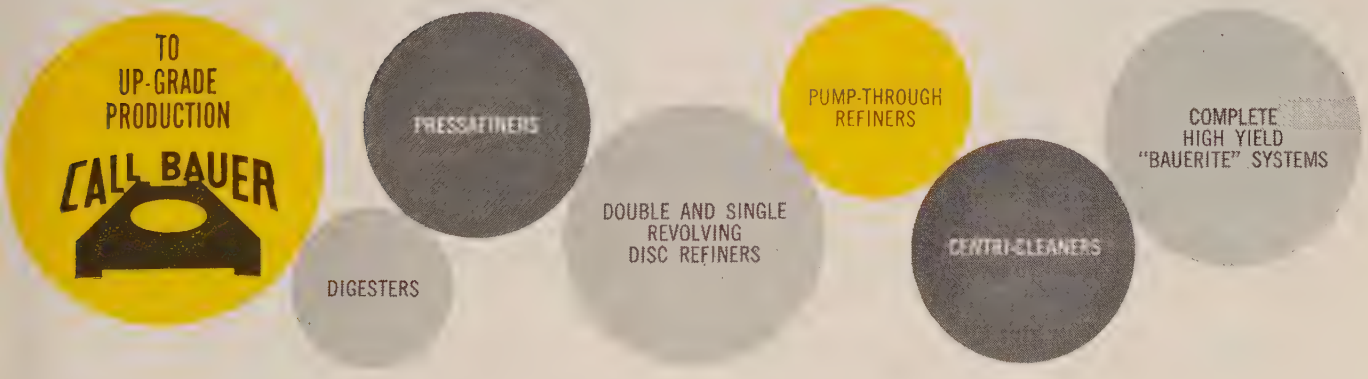

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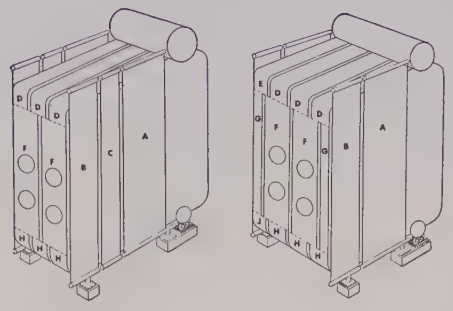

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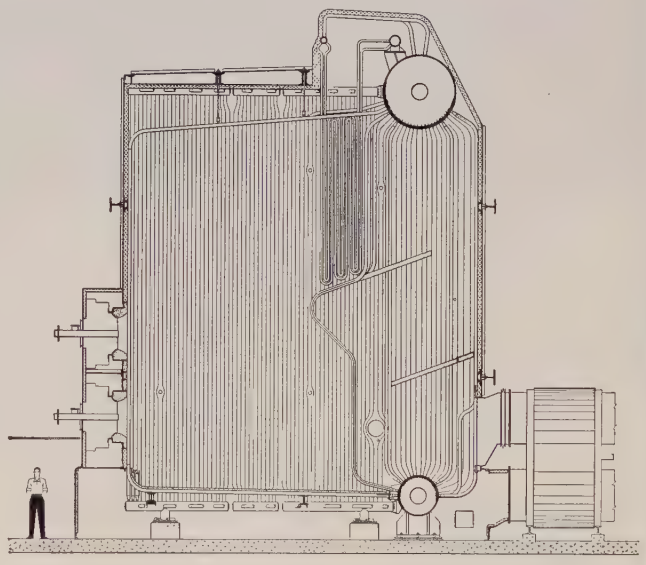

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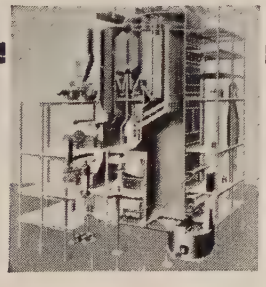

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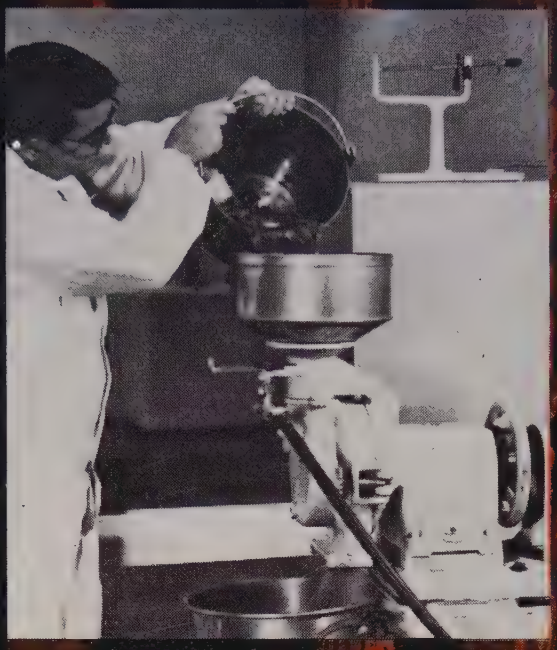

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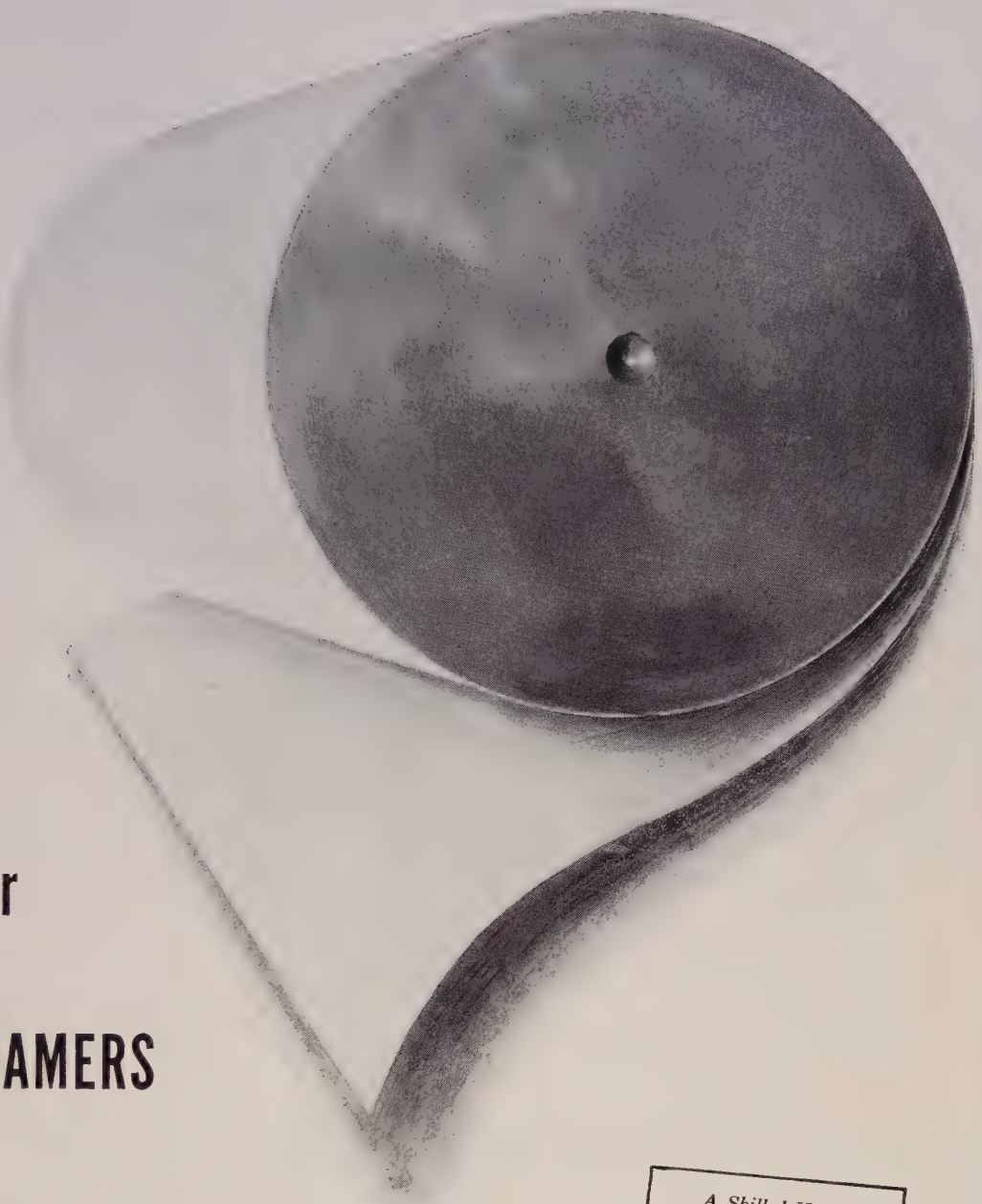

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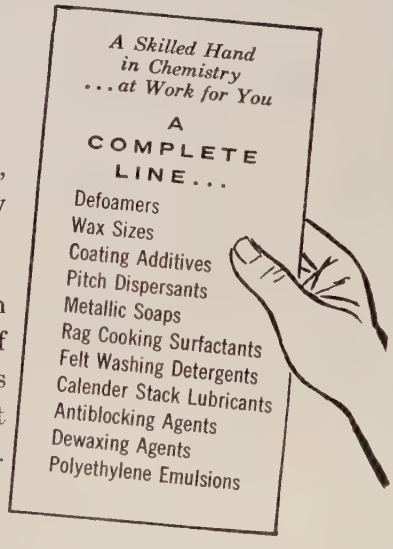

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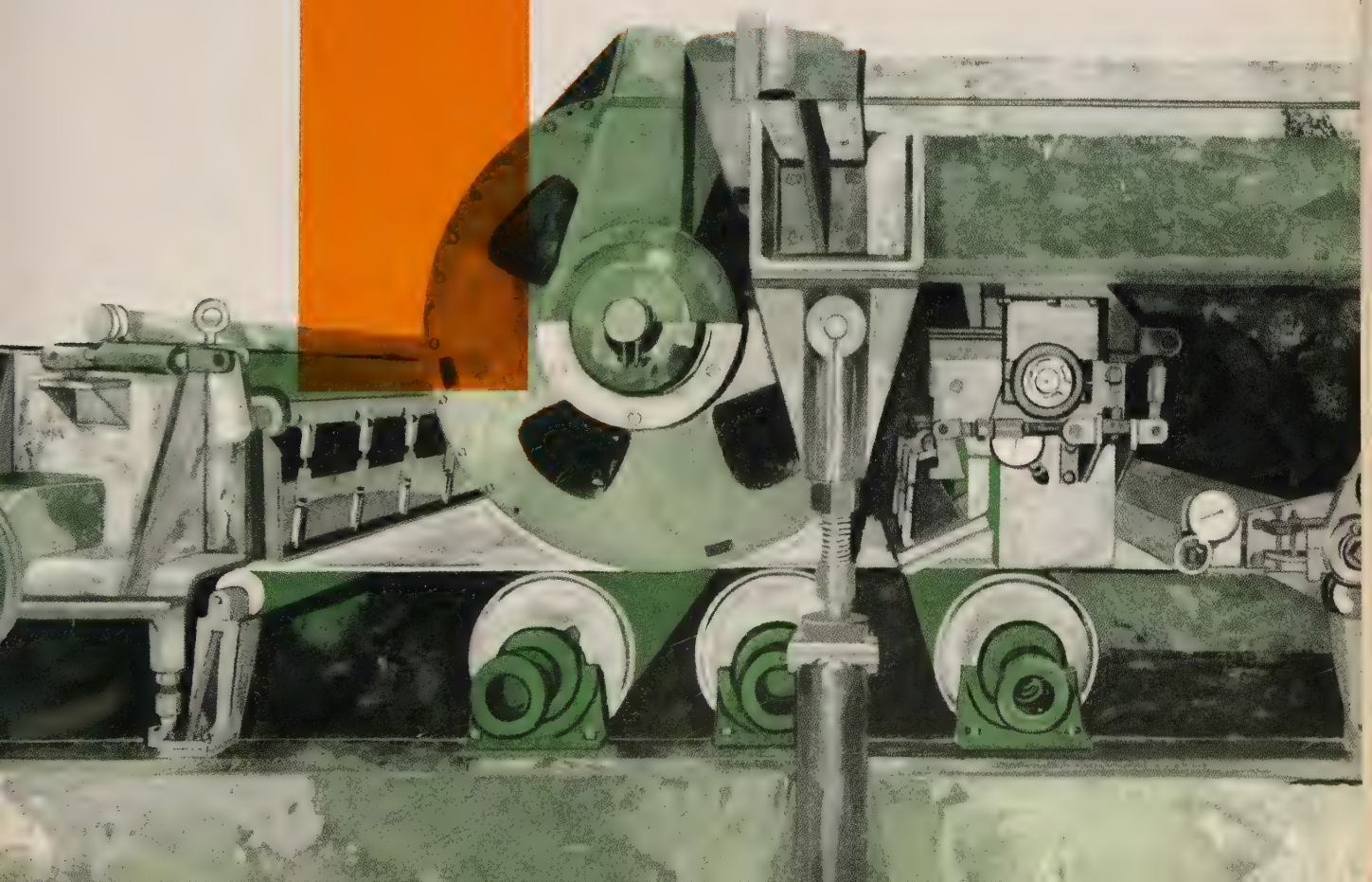

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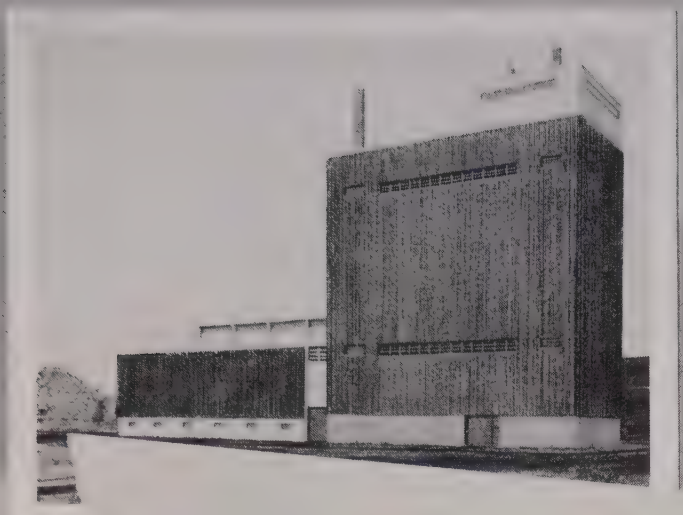

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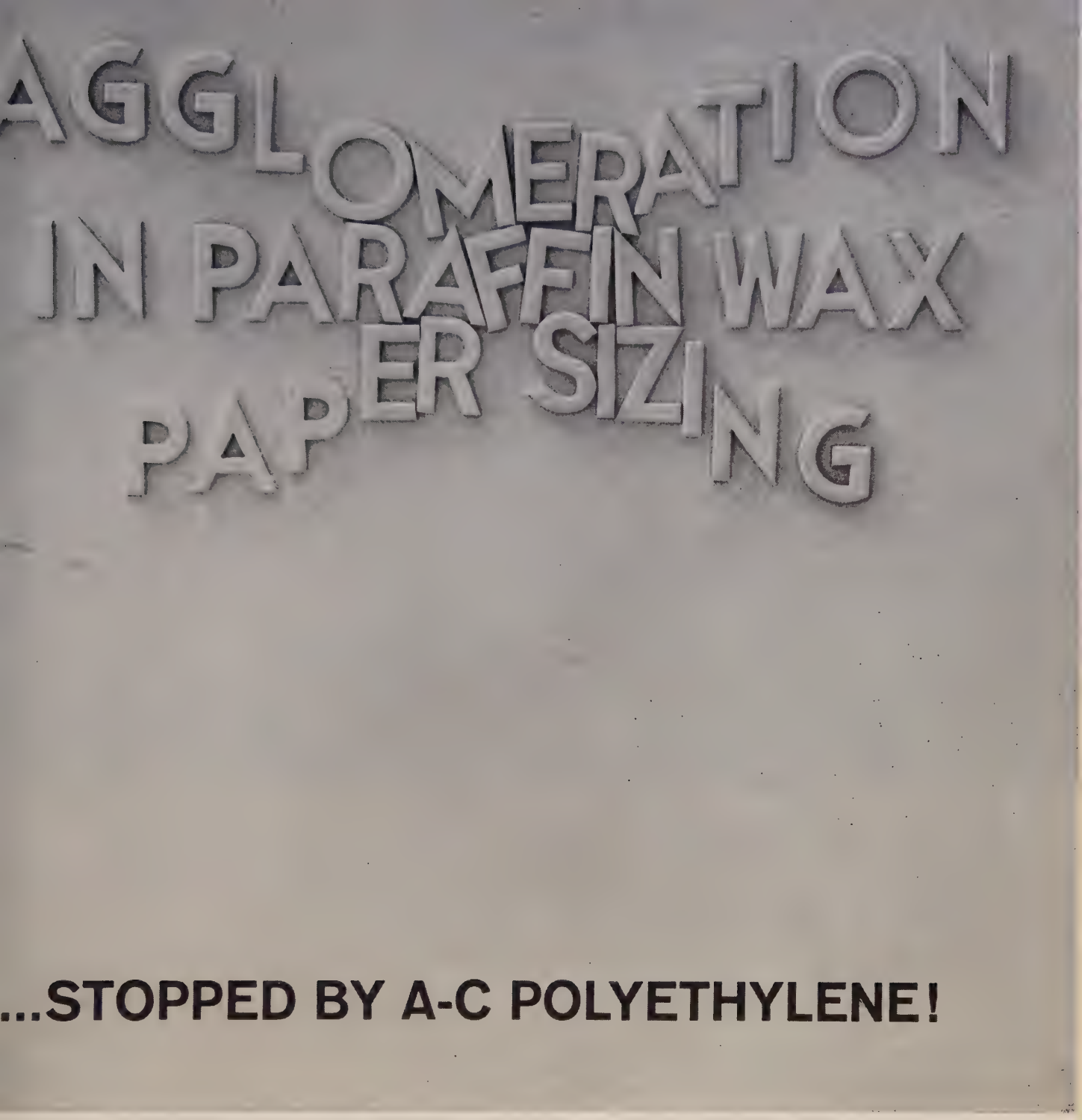

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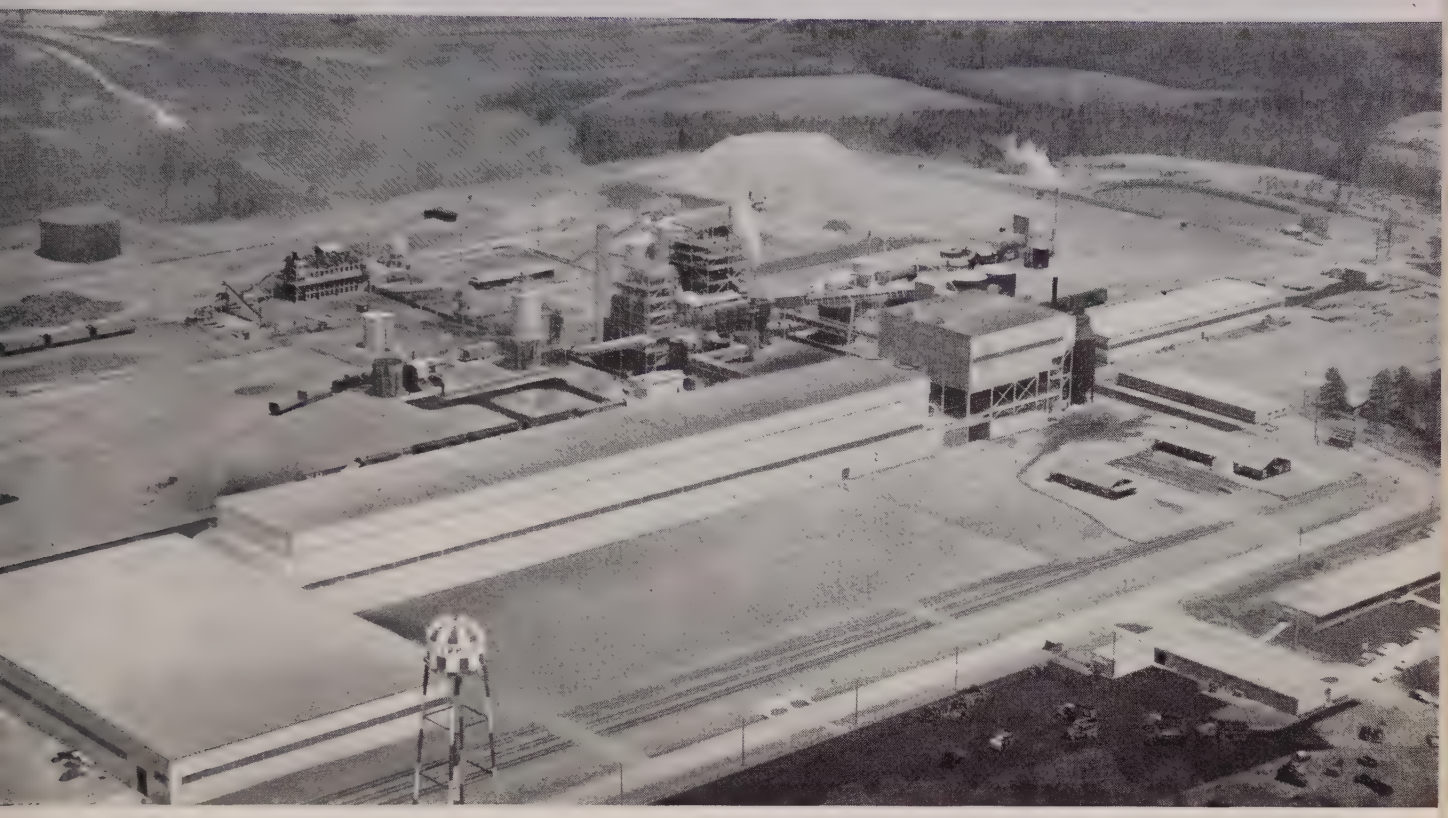

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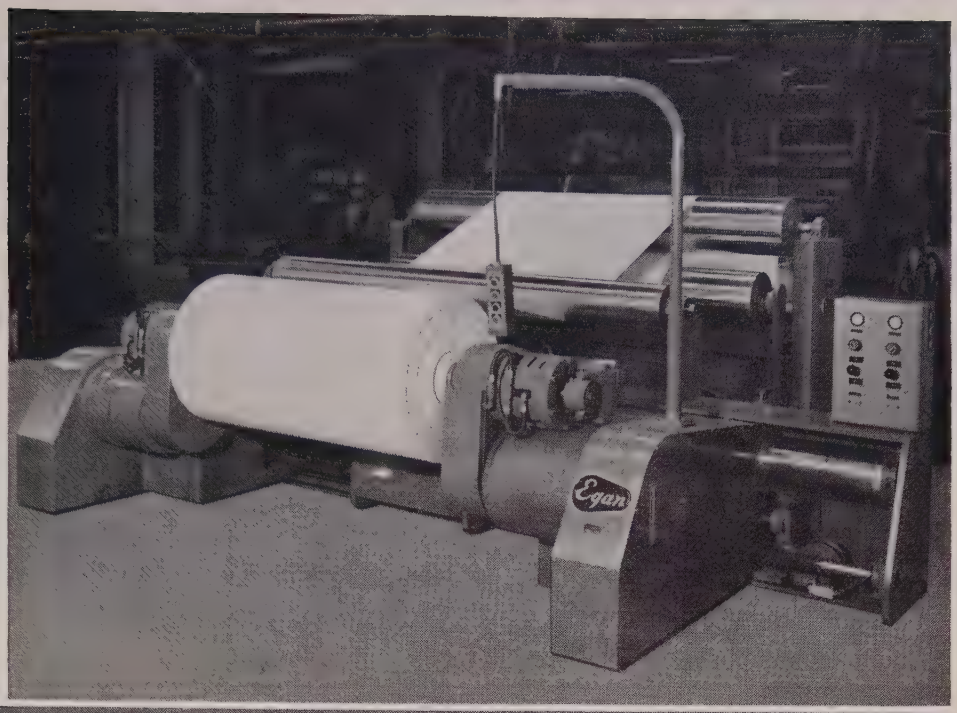

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D. N. Obenshain, W. Va. Pulp & Paper Co., Luke, Md.
L. Price, U. S. Govt. Printing Office, Washington, D. C.
J. J. Schwenkler, Container Corp. of America, Valley Forge, Oaks, Pa.
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L. M. Tyler, The Howard Paper Mills, Inc., Dayton, Ohio
W. C. Utschig, General Foods, Inc., S G-1, White Plains, N. Y.
H. W. Verseput, Riegel Paper Corp., Milford, N. J.
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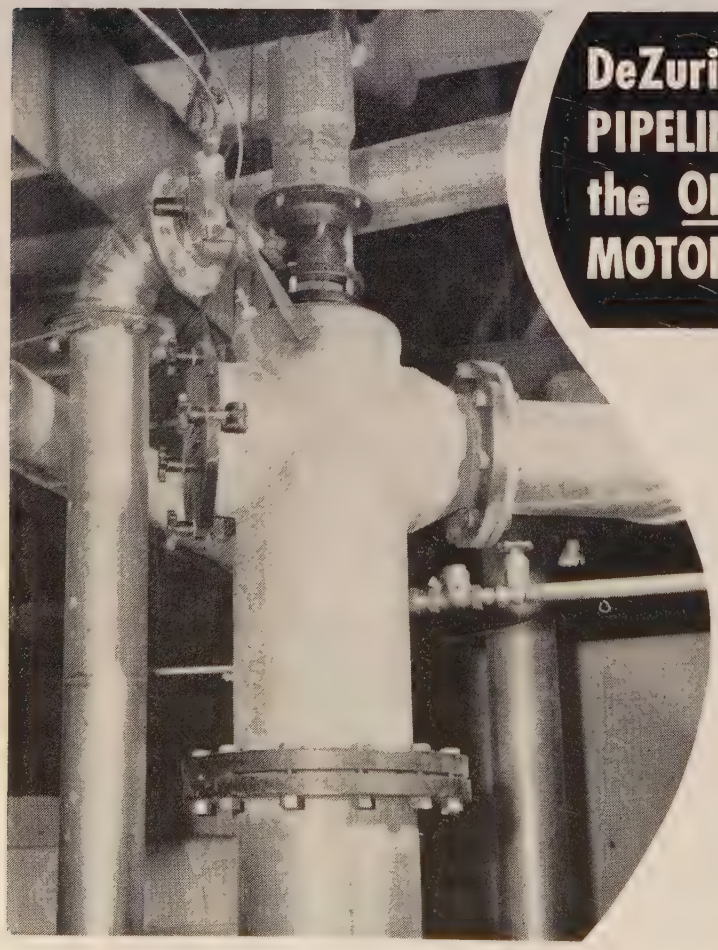

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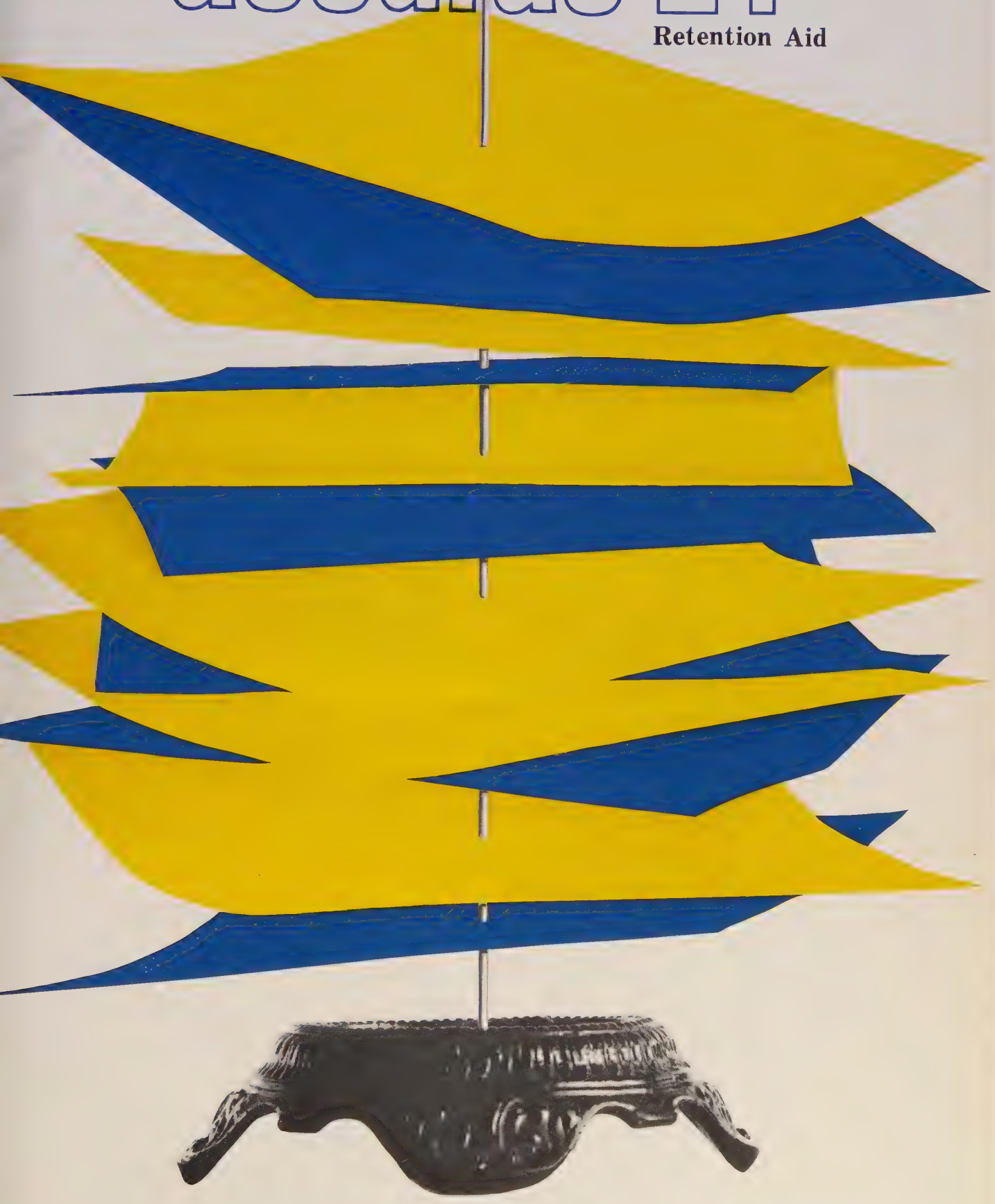

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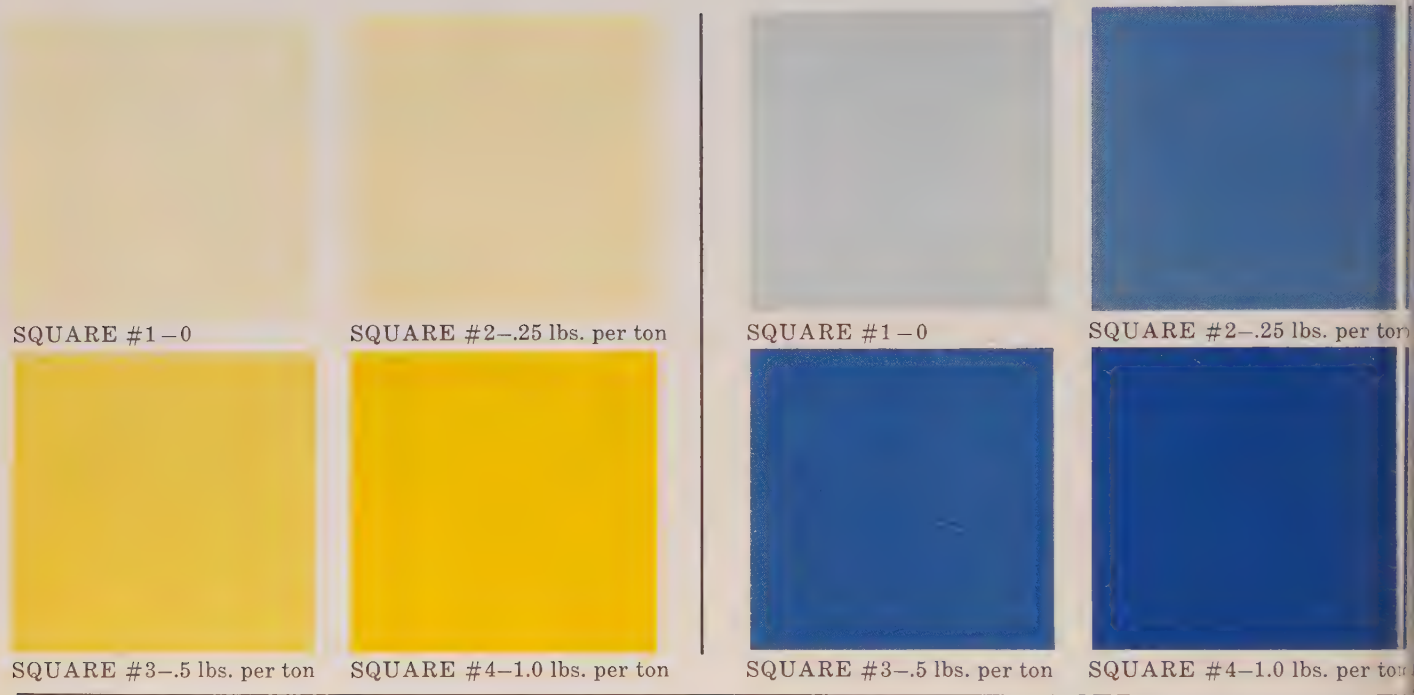
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Progress in Alkaline Pulping—1960

THE INSTITUTE OF PAPER CHEMISTRY

This report continues the series (*1–14*) on the technical and topical literature reporting progress in alkaline pulping. It reviews the literature abstracted in the Abstract Bulletin of The Institute of Paper Chemistry during the calendar year 1960.

MODERNIZATION, EXPANSION, NEW MILLS

United States

Chemical Week (*15*) mentions some of the expansions being planned by major pulp and paper mills of the United States and Canada. In a review of progress of the United States paper and board industries (*16*), 22 mills are listed with major expansion projects announced since January, 1959; 12 mills are listed with major projects scheduled for completion in late 1959 or 1960; and seven mills are given with projects under consideration. *Paper Mill News* (*17*), in its annual modernization number, presents the new mills, machines, and other expansions started up in 1959 or which are contemplated for future years. A number of the projects are described in some detail.

A description is given (*18*) of recent expansions at Filer City, Mich., of the Packaging Corp. of America, American Box Board Div. Dyck (*19*) reports that the new sulfate pulp mill of Bowaters Carolina Corp. at Catawba, S. C., is now in operation. A number of descriptions of the mill are given (*20–23*). The mill has been designed for an initial output of 400 tons per day of semibleached pulp. The $37 million mill will ship all of its pulp to the Bowaters mill in England.

Van Derveer (*24*) describes in detail the recent modernization program at Union Bag-Camp Paper Corp., Savannah, Ga. One of the main features of the program is the new high-speed kraft paper machine. The growth taking place at the two Gilman Paper Corp. mills at St. Marys, Ga. and Gilman, Vt., is reported (*25*). Evans (*26*) describes the modifications at Demopolis, Ala., of the Gulf States Paper Co. which now permits the mill to produce bleached fourdrinier board as well as pulp.

Diehl (*27*), Labine (*28*), and others (*29–31*) present descriptions of the expanded kraft pulp operation of the Buckeye Cellulose Corp. at Foley, Fla. The new mill has doubled its original capacity of five years ago, bringing the annual capacity to 200,000 tons of dissolving pulp or 266,000 tons of kraft paper pulp. The dissolving pulp made at Foley is used in making Tyrex tire cord and high-quality rayon fabrics.

Wilson (*32*) describes the new mill of the Waldorf-Hoerner Paper Products Co. at Missoula, Mont. The mill is producing a bleachable kraft pulp, part of which goes to the paper mill directly while the other part is dried by a new process and stored. Johns-Manville Corp. (*33*) is utilizing lodgepole pine as a raw material at their new plant at Klamath Falls, Ore. The mill is expected to produce about 400,000 sq. ft. of insulating board per day.

Canada

Price (*34*) summarizes the major construction and modernization projects being carried on by pulp and paper companies of Canada. Thirty-six companies have projects under way or definitely scheduled for 1961–62, 31 companies had recently completed projects, and nine companies were planning projects for the future. Taylor (*35*) lists the expansion programs now in progress in Canada and includes the cost, completion date, and a brief description of each project.

A Swedish firm is building a mill for Nova Scotia Pulp, Ltd. at Point Tupper, N. S. (*36*). The $40 million mill will produce high-quality bleached pulp and will have a capacity of 350 ton per day. Shaw (*37*) reports that among the expansion plans in British Columbia is included the kraft mill of Celgar, Ltd. The rebuilding of the Woodfibre (B. C.) mill of Rayonier Canada, Ltd., converting the existing sulfite mill to a kraft mill, is described (*38*).

Mexico

A description is given (*39*) of the San Rafael mill of Mexico's biggest pulp and paper company, Cia. de las Fabricas de Papel de San Rafael y Anexas, S. A. The mill produces kraft, sulfite, mechanical, and semichemical pulps.

Europe

A joint Norwegian-Finnish mill is being planned for construction (*40*) at Kirkenes, Norway. Some of the details of the kraft pulp and paper mill are given. Lindberg (*41*) describes the kraft pulp plant Kaukopää Mills of Enso-Gutzeit Oy, Europe's largest kraft mill, in Finland. New installations at the mill of Svenska Cellulosa Aktiebolaget in Munksund, Sweden, have resulted in an increase in kraft pulp capacity from 70,000 to 100,000 tons annually (*42*). A description of the expansions at two Swedish mills, Dynas AB and Svanö AB, is presented (*43*). The mills make kraft and sulfite pulp and a wide range of kraft papers. Wilson (*44*) describes the operations (particularly of the kraft and two-stage sodium-base sulfite pulping) at Stora Kopparbergs Bergslags AB. Skutskar mills, Skutskar, Sweden. Mititelu (*45*) reports on gradual technological improvements made between 1955 and 1959 at the "Reconstructia" mill in Rumania. These changes have resulted in significant savings of fibrous and chemical raw materials.

Asia

A newsprint mill recently established near Khulna, East Pakistan, is described (*46*). The mill will use domestic hardwood mechanical pulp and chemiground-

This survey for 1960 was prepared by J. R. Byrne, Research Assistant, Editorial Department, The Institute of Paper Chemistry, Appleton, Wis., under the supervision of Jack Weiner, Editor. Manuscript reviewed by Edward F. Thode, Research Associate, Engineering and Technology Section.

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wood, together with imported sulfite or kraft pulp. It is planned to replace the imported pulp with domestic kraft produced from bamboo. West Coast Paper Mills Ltd. at Dandeli, India (*47*), is presently producing writing, printing, and other papers from bamboo by the kraft process.

Fouad (*48*) gives a description of the projected mill of l'Industrie du Papier RAKTA to be built east of Alexandria on the Mediterranean. The mill will use the soda process to produce various grades of paper from rice straw supplemented by a lesser amount of reeds and imported wood pulp.

Australia

A description is given (*49*) of the developments and present operations of the Maryvale mill of Australian Paper Manufacturers, Ltd. which uses the kraft process on eucalyptus.

ALKALINE PULPING—GENERAL

A review of the activities (*50*) and a collection of abstracts (*51*) of papers at the 13th annual Alkaline Pulping Conference held in Jacksonville, Fla., in November, 1959, are available. Wenzl (*52*) presents a review of the literature of the past 20 to 25 years on the development and status of the sulfate pulping process. Two hundred and forty-eight references are given.

An operations research approach to the maximization of net dollar return from the operation of a hypothetical kraft pulping process has been developed by Carroll (*53*). Nolan (*54*) describes the digester which has been predicted for the kraft pulp mill of tomorrow. The digester is being installed in a pilot plant operation at present.

Tomlinson (*56*) discusses some of the more commonly observed differences between sulfite and kraft pulps and examines some of the underlying reasons for these differences.

Borišek (*57*) discusses some of the advances made in Czechoslovakia and other European countries in the production of high-yield pulps including high-yield sulfate pulping. It is contended (*58*) that unbleached kraft pulps should be characterized optically by their color rather than their brightness. The C.I.E. tristimulus method for color assessment and its application to unbleached kraft pulp are described. Klowak (*59*) compared the physical properties of pulps produced by direct and indirect kraft cooking methods. At normal freeness range, burst and tear were essentially equal for both methods. Direct cooks gave a pulp of slightly higher permanganate number and beating rates were found to be closely related to this property. Hartler and Sundberg (*60*) prepared acid sulfite, bisulfite, and kraft pulps from technical and laboratory chips and from damaged halves of technical chips. Kraft pulps suffered very little loss of strength due to chip damage.

Vaikhanskiĭ (*61*) reports on the use of so-called "organic cake" from an aluminum plant in the preparation of white liquor. This waste material is delivered to the Novo-Lyalin pulp and paper combine and is fed into the smelting furnaces. The white liquor prepared this way is suitable for the manufacture of kraft board, and wrapping and bag papers.

Saukkonen (*62*) presided over a panel discussion devoted to a comparison of continuous versus batchwise kraft cooking at the annual meeting of the Finnish Paper Engineers' Association. Linkhart and Tudder (*63*) report on the operation of a Pandia continuous digester producing kraft filler stock from sawdust. The sawdust can be cooked to a permanganate number 2 to 3 points higher than chips, and still bleach properly after blending.

Tucker (*64*) and Labine (*65*) describe the operation of a Kamyr continuous digester at the Demopolis, Ala., mill of Gulf States Paper Corp. The mill produces 375 tons per day from southern pine and hardwoods. A description (*66*) of the Kamyr digester at the North West Pulp and Paper mill at Hinton, Alberta, is given. The system is completely instrumented, permitting one operator per shift to produce 500 tons of kraft pulp per day.

Wenzl (*67*) describes a novel multistage alkaline digestion by which high alpha pulp for papermaking or chemical conversion can be produced. Evans (*68*), Räsänen (*69–70*), and others (*71*) present descriptions of the operation of the Sivola pulping process at Rauma-Repola, Oy, Finland. This sulfite-soda process was first installed on a mill scale at the Finnish mill in 1952. High quality pulps have been prepared from both hard and softwoods. The yield of pulp has been high, with good brightness and low bleaching costs. Stream pollution problems are comparable to those of a kraft mill and air pollution is practically eliminated.

THE PULPING PROCESS

Theoretical Studies

A literature review is presented by Rüf (*72*) on the subject of the chemistry of the sulfate process and the factors influencing the quality of kraft pulps.

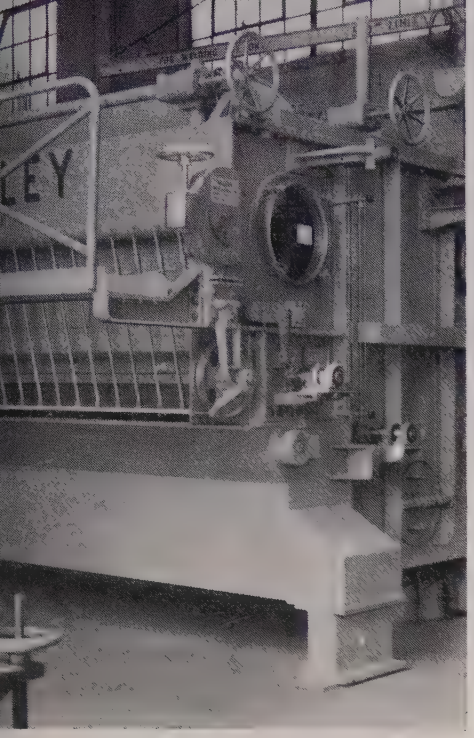
Carroll (*73*) has developed a rate expression for kraft cooking operations. A main feature is a quantitative accounting for the decreasing alkali concentration during a cook. The rate expression predicts total time for a cook to within $\pm 0.3\%$ as a function of initial and maximum temperature, time to maximum temperature, initial concentration, chemical/wood ratio, permanganate number, and yield.

Dostal, *et al.* (*74, 75*), studied the penetration of aqueous sodium hydroxide solutions into evacuated cubes of wood under a hydrostatic pressure of 1000 p.s.i. Alkali sorption in the outer layers of the wood was found to be a major factor in the distribution of alkali throughout the wood. The results indicated that pulpwood chips 0.1 in. thick and 1 in. long should be appropriate for good penetration by alkaline cooking liquors.

Hamilton and Thompson (*55*) isolated carbohydrate polymers from a variety of wood celluloses prepared through the use of holocellulose, kraft, and sulfite pulping procedures. The action of these polymers is important with respect to attempting to describe the major chemical differences between kraft and sulfite pulps.

Surewicz (*76*) found that alkaline cooking past the point at which 85% of the lignin has been removed results in preferential dissolution of the carbohydrates which then results in an increase in hardness of the pulps with attendant reductions in strength and bleaching properties.

Legg and Hart (*77*) investigated the influence of sulfides on the rate of pulping of jack pine and Douglas-fir and on the properties of the resultant pulps. Increas-



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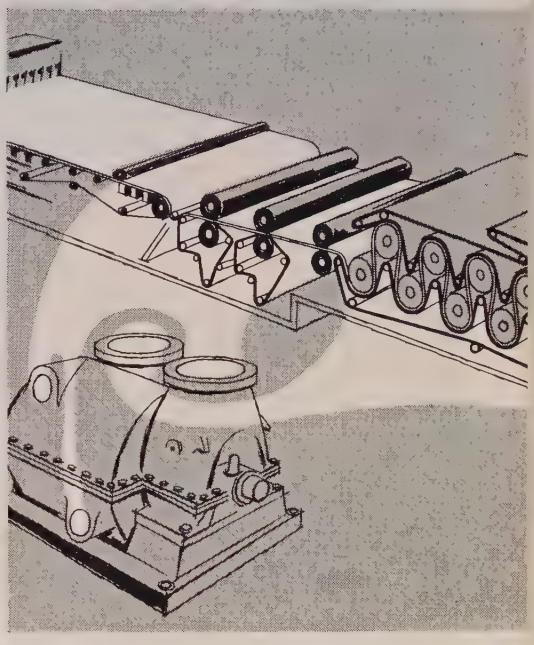

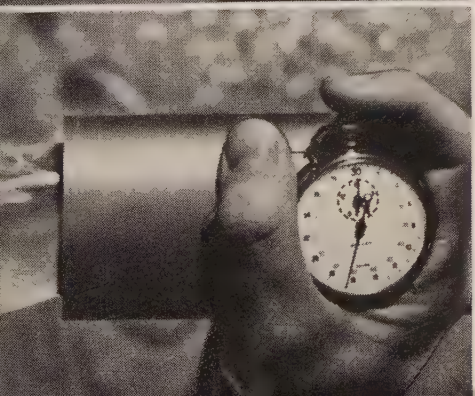

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ing the sulfide content increases the pulping rate to a maximum. Further increase in chemical not only does not accelerate the cooking rate but adversely affects the yield and properties of the pulps. Legg and Hart (*91*, *92*) also studied the influence of various cooking variables on the kraft pulping of poplar (*Populus tremuloides*) and birch (*Betula papyrifera*). They confirmed the fact that the pulping rate increases with increasing sulfide and effective alkali charge to a maximum beyond which no increase in rate or pulp quality is manifest.

Reis and Libby (*78*) report on experimental pulping of mixtures of sound, incipient decay, and advanced decay stages of pond pine infected by *Fomes pini*. An increase in decay caused a decrease in yield at approximately the same degree of delignification.

Kibrick, *et al.* (*79*), received a patent for improving pulp yields by using a cooking liquor containing predominantly polysulfides. Peckham and May (*80*) pulped a mixture of southern pinewoods using an alkaline liquor enriched in polysulfides. Compared to a normal kraft pulp, the polysulfide pulp was somewhat inferior in strength, but its screened yield was higher by up to 2%. The commercial applicability of the polysulfide pulping system would seem to depend on the relationship between the excess value of the pulp obtained over that realized from conventional kraft pulping and the additional costs imposed by the modified recovery system. Accelerated corrosion would probably be no problem.

Hartler (*81*) showed that the addition of 1% sodium borohydride to kraft white liquor increased the pulp yield by about 10% (from 46.7 to 51.2%). The addition had no effect on the strength, bleachability, or bleached yield of the pulp. The pulp was brighter and more readily beaten than ordinary kraft pulp.

Hartler and Östberg (*82*) investigated the effect of chip size, pressing, wood moisture, presteaming, preimpregnation, and cooking temperature on the amount of screenings obtained in laboratory kraft cooks. A theory of kinetic conditions during a cook is presented, in which the effects of all factors can be expressed in a single "f-value." The lower this value the greater the probability of critical conditions leading to a high amount of screenings.

Diaconescu, *et al.* (*86*), report on experiments in which sprucewood chips were pulped in a laboratory autoclave by the kraft process for 15, 25, 35, 55, and 70 min. at a maximum temperature of 165 or 170°C. and using a liquor containing 18, 20, or 25% active alkali. The shorter the cooking time at maximum temperature, the higher the yield. Pulps obtained at 165° with either 18 or 20% active alkali were essentially similar to those of ordinary kraft pulps, whereas high-yield pulps obtained at 170° with 20% active alkali showed lower breaking length and higher fold than comparable ordinary kraft pulps.

Wood Pulps

Hashimoto, *et al.* (*83*), report the yield, bleachability, and strength properties of kraft pulps made from 26 different species of hardwood. Ent (*84*) found that Surinam hardwoods behave like hardwoods of the temperate zone during pulping.

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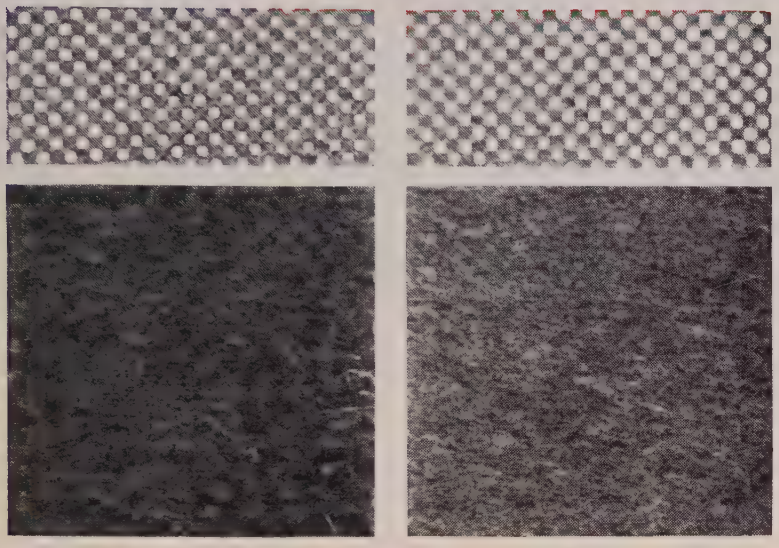

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High-yield kraft pulps had better strength properties than NSSC pulps and could be produced by a continuous process.

Eşanu, *et al.* (*85*), report on cooking experiments with blends of spruce with various amounts of beech and poplar using the kraft and soda-sulfur processes. The digestion was found to proceed independently for each wood species.

Cann and Roberson (*87*) discuss some data from the literature pertaining to the effect of active alkali on the yield and quality of pine kraft pulps in the light of experimental data gathered by themselves. Yield data agreed quite well. McKee (*88*) investigated the characteristics of small slash pine stems that influence their desirability as a pulping material. The wood exhibits certain physical characteristics different from those of normal-size wood but no special pulping provision should be required, especially when the proportions of undersize wood to normal wood are small.

Havránek and Gajdoš (*89*) describe the operation of a Czechoslovakian mill which manufactures rayon pulp from beechwood by the prehydrolysis kraft process. The prehydrolysis step is carried out at 165°C. for 1.0 to 1.5 hr. The prehydrolyzate is drained off and the white liquor is charged to the digester. The total cooking cycle lasts 14 hr. Gajdoš (*90*) reports that some of the advantages of the two-stage process for beechwood are that a variety of factors in both stages can be selected to give the desired properties to the pulp, and that the noncellulosic residue may be utilized through fermentation, heat recovery, and chemical recovery.

Guha and Mathur (*93*) prepared satisfactory kraft pulps in the laboratory from Indian poplar (*Populus ciliata*) using 22 to 24% chemical at 153°C. The pulp appeared to be suitable for use in writing and printing papers but would have to be mixed with a long-fibered pulp for production on a commercial paper machine. Tosaka (*94*) prehydrolyzed chips of Shirakaba birch with water, acetic acid, or sulfuric acid and then subjected them to sulfate pulping at 170°C. for 2.5 hr. at a wood:liquor ratio of 4:1 using a liquor of 30% sulfidity and up to 25% active alkali. As the severity of the prehydrolysis increased, the yield, cellulose content, and pentosans decreased.

Kawase, *et al.* (*95*), studied the chemical and physical properties of kraft pulps prepared from five Japanese softwoods and five Japanese hardwoods. There were no appreciable differences among species within each group. Vámos and Mérö (*96*) studied two kinds of pulp blends: one was straw kraft and softwood sulfite and the other straw pulp and softwood kraft. Sheets prepared from mixtures containing 20, 40, 60, and 80% straw pulp were tested. Burst, breaking length, and double fold usually exceeded the values predicted from the respective component properties, whereas greaseproofness and writability generally approached the value of the weaker component.

Kozmál and Bučko (*97*) present results of pulping trials of acaciawood by the kraft process. Pulps were obtained in a yield of 38.9%. The pulps are darker than softwood pulps, but are easily bleached to a higher degree of brightness. They are recommended for the manufacture of special type papers.

Nolan (*98*) obtained a patent for a pulping process in which the chips are subjected to an alkaline solution for a short time, split, and then subjected to a purification treatment in a solution of sodium hydroxide and sodium sulfide at 300 to 400°F. Marpillero (*99*) received a patent for his process in which wood is treated with caustic soda, drained, treated with a chlorate in an acid medium, defibrated, and bleached. Wilson, *et al.* (*100*), studied five British Columbia wood species in regard to their sulfate pulping chacteristics. All the strength properties of the pulps were either equivalent or superior to the best data reported in the literature.

Zaĭtseva (*101*) reports that extracted larchwood chips are suitable for the manufacture of hard, soft, and dissolving grade kraft pulps and good quality building boards. Fahey and Setterholm (*102*) report that linerboards equivalent to commercial southern kraft boards were made from mixtures of 25% sweetgum sulfate and 75% southern pine sulfate pulp. Guha, *et al.* (*103*), prepared high alpha-cellulose pulp from salai wood by prehydrolyzing the wood with water, digesting by kraft pulping methods, and bleaching. The dissolving pulp produced in 30% yield was found to have the requisite chemical purity and brightness for rayon manufacture.

Agricultural Residues, Grasses, etc.

Atchison (*104*) presents a report which concerns the application of the continuous pulping method to rice straw, bagasse, and reeds. In general, it was found that the method is suitable. The chemical consumption, yields, and strengths of pulps from straw and reeds are probably affected adversely by not cleaning the material before pulping.

Fahmy and Ashmawy (*105*) investigated the effect of pulping variables when pulping bagasse by the kraft and single and two-stage soda processes. The effect of depithing on pulp properties was also studied and the data revealed no significant difference in strength and other mechanical properties. They suggest that dirt and dust might be responsible for the strength reduction commonly encountered with pulp from undepithed bagasse. Locus (*106*) prepared viscose-grade pulp from bagasse by the prehydrolysis-sulfate process in yields of about 33%, comparable with that from wood. The characteristics of the pulps were satisfactory for the manufacture of viscose rayon. Knapp and Wethern (*107*) obtained a patent for a pulping process for bagasse which comprises mixing the plant material with sodium hydroxide liquor, heating the mixture under pressure to 130 to 210°C. over a period of 45 min., and maintaining this temperature under pressure for 1 to 25 min. An easily bleached papermaking pulp can be produced in this manner.

Govil (*108*) produced a pulp suitable for the rayon industry from groundnut shells by a water prehydrolysis-sulfate process. Nepenin, *et al.* (*109*), found that the best means for the integral utilization of stump wood is semikraft pulping with recovery of sulfate soap and turpentine. Jain (*110*) pulped jute in a two-stage kraft process in which the cooking liquor used in the first stage was the black liquor derived from a previous second stage. Compared with a conventional kraft pulp, the bleached yield was higher and the pulp strength greater.

Fouad, *et al.* (*111*), report on soda and kraft pulping studies utilizing certain domestic and foreign rice straws. No unusual equipment or techniques are needed to produce quality pulps from this material and,

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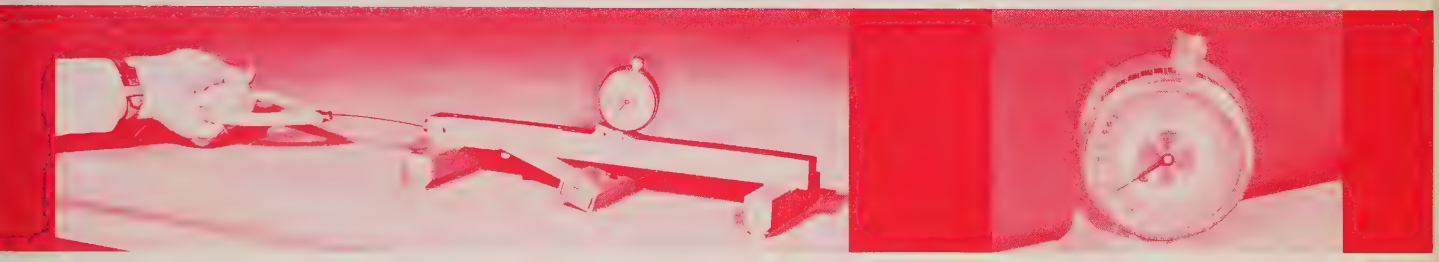

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either alone or in blends with wood pulps, these pulps can be converted to a variety of papers on a paper machine. Jain (*112*) carried out soda pulping trials on bamboo dust left from the preparation of bamboo chips. The pulp was suitable for cheap-grade wrapping papers, cheap board grades, and as filler in strawboard.

A description is given (*113*) of the operation of a Pandia continuous digester in a kraft cook on wood waste at Potlatch Forest, Inc., Lewiston, Idaho. Martin (*114*) found that sawdust chips gave kraft pulp with bursting and tearing strengths of 80 and 85% of those for regular chip pulp.

Constantinescu (*115*) describes the manufacture and characteristics of various paper and board qualities produced partly or entirely from reed kraft pulp. Burova, *et al.* (*116*), studied the papermaking merits of reed from the Danube Delta. The characteristics of sulfate pulps were the same for various biotypes, whether derived from flooded or unflooded banks, marsh land, or floating reed islands. Iliescu (*117*) reports that comparative impregnation and pulping trials with Danubian reed cane and cereal straw confirmed the importance of the different morphological structure of the two plants, in that the reed required longer periods of impregnation to yield pulps of comparable strength. Kraft pulps of good strength properties were obtained with 60 min. impregnation for straw and with 150 min. for reed. Iliescu (*118*) later blended reed and spruce kraft pulps and found that increased amounts of reed pulp reduced the dynamic strength properties but did not affect the static strength properties to the same extent. In many instances it was advantageous to mix highly beaten reed pulp with mildly beaten spruce pulp.

THE LIQUOR CYCLE

Stone and Clayton (*119*) report on a comparative study of the degradation of carbohydrates by kraft and soda liquors. Chemical analysis and measurement of physical properties showed that kraft liquor does not cause less degradation than soda liquor. At medium and high yields, the strength of the two kinds of pulps of equal time and lignin content are identical. Maksimov (*120*) determined the effect of sulfidity on the amount of sulfur compounds formed during kraft cooking. Methyl mercaptan constituted the major fraction of noncondensing sulfur compounds, and the yield increased by factors of 1.5 and 1.2 with increases in sulfidity from 20 to 30% and from 30 to 40%, respectively.

Moscu (*121*) discusses the theoretical and practical variables affecting the diffuser washing of brown stock with emphasis on duration, temperature, pressure, and diffuser design. Grabovskiĭ and Namestnikov (*122*), using a laboratory-model diffuser washer, found that the washing process occurs in a highly nonuniform way. Efficiency was improved by charging the diffuser so as to pack the pulp more densely along the walls and by thoroughly mixing the pulp suspension after withdrawal of the strong black liquor. Cox and Reaves (*123*), studying washing with continuous rotary washers, determined the best sustained washing rate and developed optimum washing procedures.

Baklien (*124*) noted that in alkaline pulping operations of eucalypts using a large amount of sodium hydroxide, the discharge pipes were fouled with a green deposit. To keep down the amount of this deposit, it was suggested that the temperature and pH be kept high in the early stages of cooking, that blended chips be used, and that the material settling out in the liquor-storage tank not be burned.

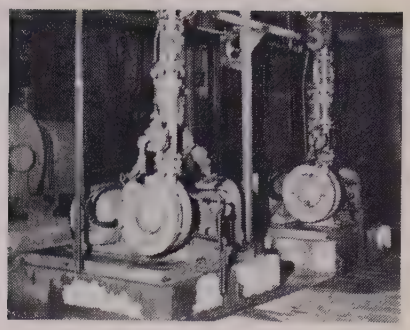
Swartz, *et al.* (*125*), describe the system at Bowaters Southern Paper Corp. in which sulfuric acid is used as makeup sulfur to permit recovery of spent cold caustic liquors, increase sulfidity of kraft liquors, and to maintain liquor sulfidity at a desired level. Han and Whitney (*126*) determined the solubility of sodium carbonate in sodium sulfide solutions at temperatures from 5 to 90°C. and with a sulfide content from 2 to 10%. These data were applied to the kraft-neutral sulfite cross recovery with respect to fractional crystallization and partial solution.

Boyer (*127*) describes the Western Precipitation recovery system which utilizes the crystallization separation of the sodium carbonate from the sodium sulfide of the smelt and reacts all of the separated sodium sulfide with the spent liquor sulfite sulfur through an oxidation-reduction reaction known as the Bradley process. The reacted liquor is evaporated and burned in inexpensive kraft equipment. High sulfur, soda, and heat recoveries are possible with this system.

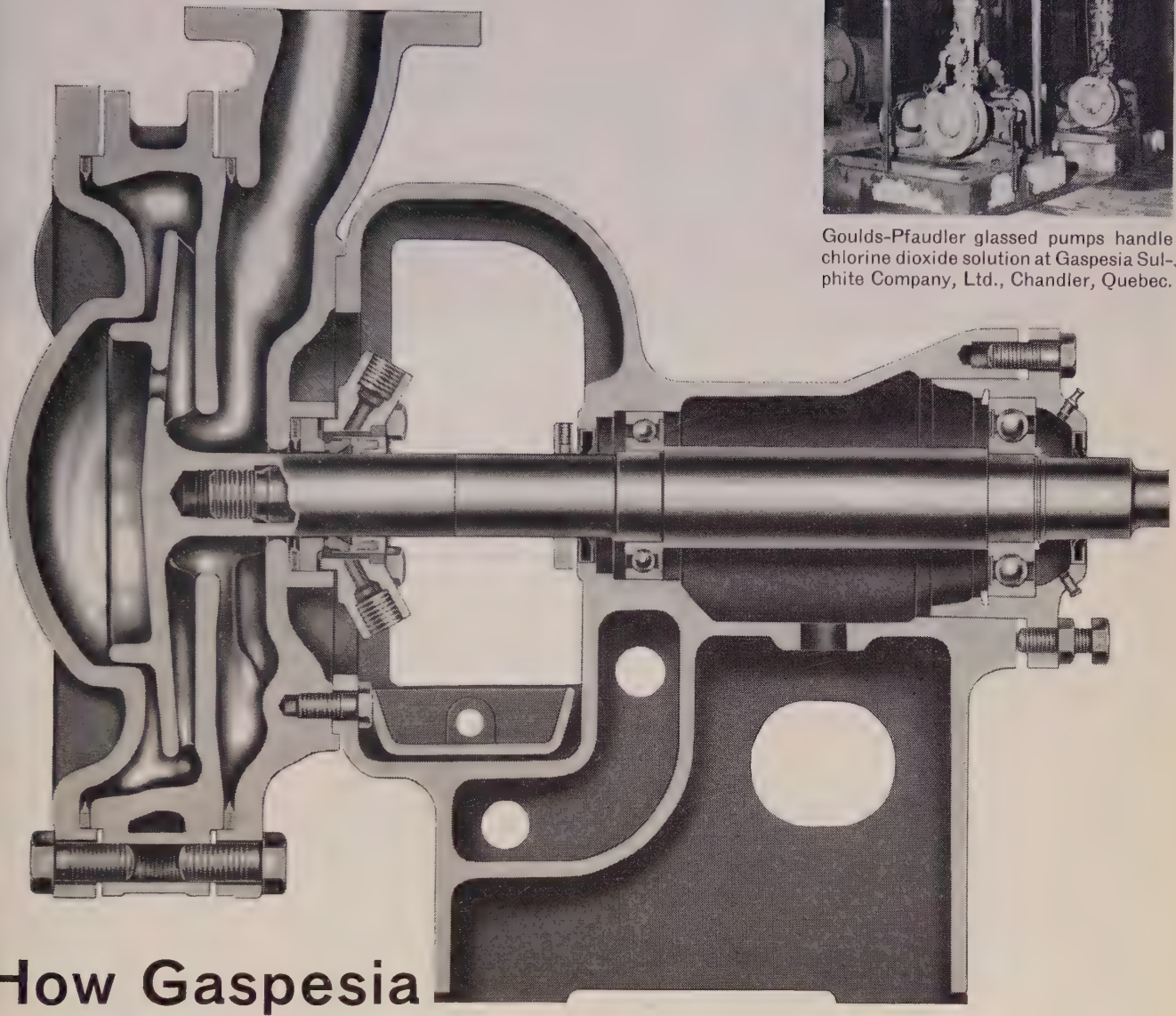
Kennedy and Jernigan (*128*) patented a process in which black liquor is introduced into an electrolytic cell in which the liquor is in direct contact with the cathode and forms the sole electrolyte for the cell. Direct current is passed through the cell and lignin is deposited on the anode with concentrated alkaline liquor produced adjacent the cathode. Collins (*129*) obtained a patent for a process of recovery of black liquor which includes an oxidation step before evaporation.

Fones and Sapp (*130*) investigated the oxidation of black liquor in a pressure vessel with pure oxygen as a possible means of circumventing some of the problems occurring when air is used. The addition of oxygen at the end of a kraft cook successfully reduced the sodium sulfide content of the liquor but oxygen consumption was high and a significant reduction in pulp strength and brightness was apparent. Murray (*131*) studied the kinetics of black liquor oxidation over a temperature range of 122 to 196°F. and sodium sulfide concentrations up to 16 g.p.l. The rate of oxidation of weak liquor at sodium sulfide concentrations above 2.5 g.p.l. is maximum between 142 and 160° with air, and at about 160° when pure oxygen is used.

Jurgensen, *et al.* (*132*), discuss the installation of mesh entrainment pads in a multieffect sulfate black liquor evaporator. Entrainment losses can be reduced with a resultant reduction in B.O.D. loadings and an increased operation period between boilouts. Cyr and Harper (*133*) present a preliminary survey of the major problems in designing multiple-effect evaporators including scaling, tubes and tube life, and cleaning procedures. Some of the factors affecting the efficient evaporation of black liquor from the pulping of rice straw were investigated by Lengyel and Vercsegh (*134*). Lengyel (*135*) investigated the problem of silica in black liquors from the pulping of agricultural residues and its effect on the evaporation and causticizing operations. Experimental data indicate that liquors containing up to 6 to 8 g. of silica per liter can be evaporated without troubles by addition of excess sodium hydroxide. Silica contents of this order do not



Goulds-Pfaudler glassed pumps handle chlorine dioxide solution at Gaspesia Sulphite Company, Ltd., Chandler, Quebec.



How Gaspesia keeps ClO_2 from gobbling up its pumps

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affect seriously the causticizing treatment but increase the volume of lime mud by about 100%.

Brown and Kleinman (*136*) discuss maintenance procedures for black liquor evaporators including tube cleaning, tube replacement, body inspection, piping, condensers, air ejectors, pumps, and mixed liquor operation.

First, *et al.* (*137*), report on studies covering the operation of the Buffalo Forge Co. TE Washer designed to reduce the emissions from recovery boilers and includes operating data from applications of the unit in a kraft mill. Smith (*138*) reviews some of the improvements developed by Combustion Engineering in the field of black liquor recovery.

According to a patent by Hutton (*139*) the char bed temperature in a recovery furnace is controlled by recirculating cooled flue gases so as to reduce the sublimation of chemicals in the inorganic ash residue. Lonngren (*140*) patented a process wherein partially burning black ash is maintained in a fluidized state, withdrawn and mixed with black liquor to form additional black ash, passing the total black ash into the drying zone and into the heating zone for partial combustion, and continually withdrawing dried black ash product.

Christiani, *et al.* (*141*), review the progress during the last 12 years in kraft mill operation and indicate current trends in continuous causticizing practice. Through continued attention to sources of chemical losses, recovery efficiencies of over 99% on soda and 97% on lime have been achieved. Fenwick and Thomas (*142*) report on tests for heat and chemical recovery performed on a dissolving tank stack economizer. Savings per year were calculated to be 50% of the installation cost.

Wiberg (*143*, *144*) compared two causticizing systems which differed only in that one did and the other did not use green liquor clarification. It was concluded that there is very little chemical superiority in the end use of reburned lime which has had the benefit of green liquor clarification.

Letonmyaki, *et al.* (*145*), investigated the composition of the organic fraction of pinewood black liquor which constitutes approximately 50% of the wood weight. Lignin and ligninlike compounds constitute about one half of this fraction with the fraction derived from carbohydrates constituting 16.5 to 16.9% of the wood weight. Analysis of this fraction after its separation from lignin showed that it contains mainly hexosan degradation products. Ora (*146*) determined total sulfur in black liquor by burning it in oxygen and determining the sulfuric acid formed by volumetric means.

Bilberg (*147*) compared three potentiometric methods for the determination of sulfides in black liquor. The mercuric chloride method was found to be the most reliable. Two methods for determining polysulfides were developed which give results in fair mutual agreement. One resembles Kurtenacker's determination which involves the addition of an excess of sulfite and the potentiometric titration of the thiosulfate formed. The other method comprises the addition of copper ions, the isolation and dissolution of the copper sulfide formed, and the collection and iodometric titration of the hydrogen sulfide evolved. A paper by Bilberg and Landmark (*148*) also deals with these two methods for determining polysulfides in black liquor.

Saltsman and Kuiken (*149*) describe an analytical method for the estimation of tall oil in black liquor which involves extraction of the oil from an acidified aqueous-acetone-alcohol solution in which degraded lignin residues are soluble. Data are given on analytical precision, recovery of tall oil added to the system, and characterization of the isolated product.

A description is given (*150*) of the tall oil fractionation process at Union Bag-Camp Paper Co. in Savannah, Ga. It is a blocked system in which the same tower is used first to separate purified tall oil into rosin and fatty acid fractions, and then, while the original tall oil flow is blocked, to fractionate the fatty acids. Wafer (*151*) predicts possible future production of tall oil up to 1965 and discusses markets for tall oil products. The constant decline in gum rosin production and an indication of a similar development in wood rosin may lead to tall oil becoming an alternate source of supply. Ryczak (*152*) discusses the reasons for using a batch rather than continuous system for the production of tall oil. An installation now in operation has a yield of 95%, representing at least 5 or 6% higher than generally credited a batch process. Modern equipment and improved operational technique is credited with this improvement.

Agranat (*153*) describes the preparation of phytosterol from sulfate soap at the Segezh mill. The possibilities of producing phytosterol from tall oil is also discussed. In a later paper (*154*) the author

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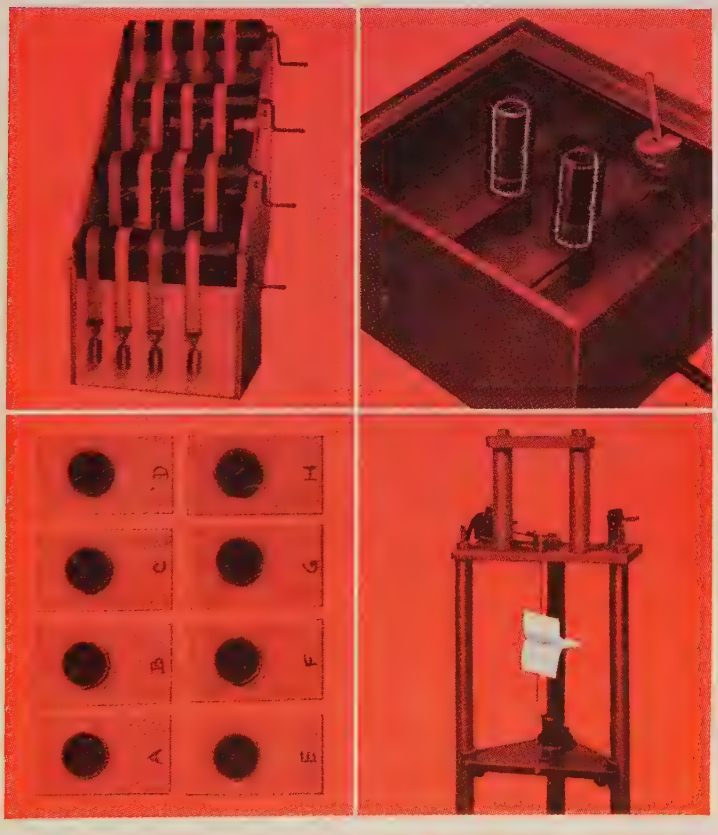

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discusses the effect of modern processing methods on the properties of phytosterols in sulfate soap.

Komshilov, *et al.* (*155*), present recommended modifications of the VTU methods for the analysis of sulfate soap and tall oil. A method for the purification of sulfate soap from black liquor is described (*156*). The tall oil obtained from this method is characterized by its light color and liquid consistency. The method reduces the consumption of sulfuric acid by about 30%.

Pesch (*157*) reports that favorable economic conditions and other basic factors have fostered a remarkable growth in the sulfate pulp and kraft paper industries. The substantial amounts of by-products now being recovered have greatly reduced the amounts of solid, liquid, and gaseous materials lost from kraft mills. Tall oil and turpentine production and lime recovery are examples of this.

Goheen (*158*) obtained a patent for making methyl mercaptan by reacting black liquor with elemental sulfur or sodium sulfide at a temperature of 170 to 500°C. for a time sufficient to produce a substantial amount of the material while leaving a pumpable residual solution. Cisney and Goheen (*159*) received a patent for preparing dimethyl sulfide by reacting black liquor with methyl mercaptan at pH 10 or greater and at a temperature of 200 to 350°C.

Crown Zellerbach recently built a plant at Bogalusa, La., for the preparation of chemicals from black liquor. The plant is designed to produce 5 million lb. per yr. of dimethyl sulfoxide, 10 million lb. per yr. of dimethyl sulfide, and 1 million lb. per yr. of methyl mercaptan.

Sandborn and Nall (*161*) received a patent for a process in which the black liquor is concentrated, delignified, reacted with bisulfite ion and acetone to produce carboxylic acids in a first phase and an acetone–sodium bisulfite addition product in a second phase. In a second patent (*162*) the delignified concentrated liquor is reacted with acetone and either sulfur dioxide or sulfurous acid to produce an aqueous solution of monocarboxylic acids and a precipitate of an acetone–sodium bisulfite addition product. Acetone is then recovered from an aqueous solution of the addition product and sodium carbonate.

Findley (*163*) investigated possible methods of recovering organic products from black liquor with respect to the economic feasibility of the method. The data indicate that it is possible to use a portion of the liquor to produce acetic and formic acids and thiolignin with cooking chemical recovery.

Enkvist (*164*) outlines some of the chemicals in black liquor which could be recovered other than those now being recovered commercially. Pearl and Beyer (*165*) investigated the suitability of kraft spent liquor from the pulping of aspenwood as a source of *p*-hydroxybenzoic acid and other aromatic compounds. The liquor proved satisfactory when compared to aspenwood itself.

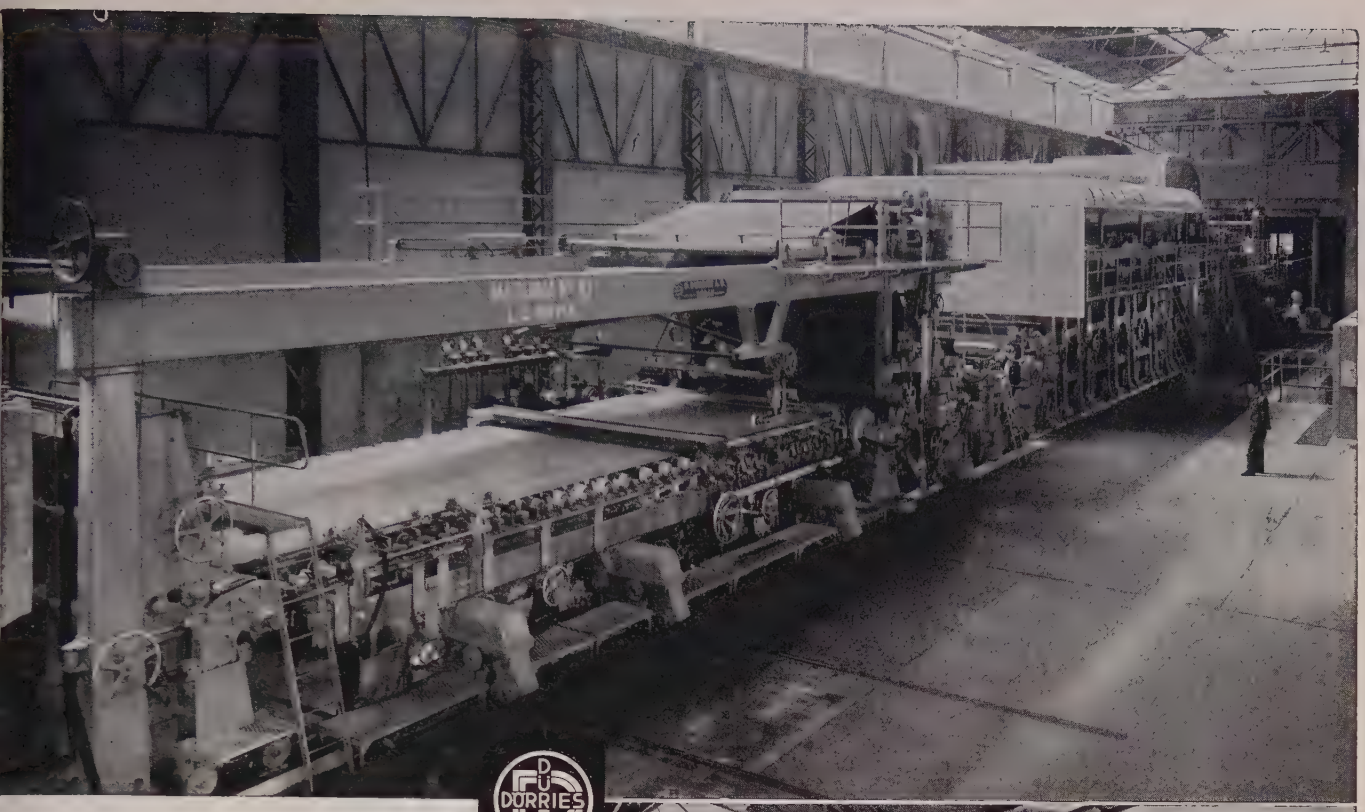
STREAM AND AIR POLLUTION

Berger (*166*) presents a summary of surveys to determine the current status of methods for removing suspended solids from the effluents of some southern pulp and paper mills. It appears that relatively short period sedimentation is capable of removing the bulk of the solid material from the effluents. Stops and Agar (*167*) describe the steps taken by the Maryvale mill of Australian Paper Manufacturers Ltd. to meet the effluent disposal regulations of the Victoria Rivers and Water Supply Commission.

Othmer (*168*) points out that the amounts of acetic and formic acids discharged with the effluents of alkaline pulp mills exceed the total demands of the chemical industry. These acids and their salts account for about 50% of the stream pollution caused by pulp mills. Maksimov and Modzelevskaya (*169*) studied the effects of air consumption and temperature on the oxidation of a kraft mill effluent characterized by a high organic content, high B.O.D., high alkalinity, and a strong odor. Acidification of the material, followed by aeration, is recommended.

Sullins (*170*) reports that the most economical methods of reducing B.O.D. of pulp and paper mill effluents are biological, including aerobic and anaerobic decomposition. The method which has proved most successful is the activated sludge process.

Lardieri (*171*) reports on a survey of methods to combat air pollution used by 58 United States kraft mills which showed that most of the mills use electrostatic precipitators. The author concluded, on the basis of this survey, that the kraft industry does not have a critical air pollution problem at this time. Rabkin and Crommelin (*172*) present a guide to the preventive maintenance of the electrostatic precipitator. Meinhold and Goodwin (*173*) describe the electrostatic precipitators used at the Jacksonville, Fla. mill of St. Regis Paper Co. The equipment is being employed successfully in the prevention of air pollution and they



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are recovering 75 tons per day of salt cake for reuse in the pulping operation.

Bernhardt and Buchanan (*174*) discuss experiences in trying to solve a problem of chemical losses from the dissolver stack at a kraft mill. Losses averaged 4020 lb. per day as sodium sulfate or 17.1 lb. per ton of pulp produced. A knitted-metal mist eliminator was tried and proved to be a simple and inexpensive means of decreasing chemical losses and reducing air pollution.

BLEACHING

Veisberg and Bakk (*175*) cooked reed using 0 to 60% black liquor in the white liquor. With 40 and 60% additions at 160°C., the chlorine consumption of the resulting pulp increased by 9 and 14%, respectively, over the amount required for bleaching normal kraft pulp. At 178°, the respective increases in chlorine consumption amounted to 22 and 35%. No increase in consumption was noted with additions of black liquor of 0 to 20% at 160°, but the consumption of chlorine increased by 7% for pulp cooked at 178°.

Dahm (*176*) noted that kraft pulp can be treated with a certain amount of chlorine without causing degradation; however, this amount is appreciably less than that usually applied in commercial operation. The author suggests that the use of no more than this nondegrading amount would be of great advantage.

An extensive investigation of five hypochlorite bleaching variables and their effect on the chemical properties of hardwood sulfate pulps was carried out by Smith and Thornburg (*177*) and resulted in the following observations: Starting pH is by far the most important variable in hypochlorite bleaching. Temperature and percentage of available chlorine appear to be equal in their effect. Time has very little effect. Lyon and Salisbury (*178*) show that the effects of pH in successive hypochlorite stages are similar but not identical. The necessity is indicated for keeping the pH in all hypochlorite bleaching stages above 8 for optimum bleaching results.

A description is given by Barker (*179*) and others (*180*) of the four-stage bleach plant of the Mead Corp. at Chillicothe, Ohio. The sequence used is chlorination-extraction-hypochlorite-chlorine dioxide (CEHD). Kauffman (*181*) describes the chlorine dioxide bleaching at Brunswick Pulp and Paper Co. The facilities were changed from calcium hypochlorite with the first two stages remaining the same. The five-stage sequence is now CEDED.

Freedman (*182*), after discussing the objectives of bleaching, outlines six processes for the commercial generation of chlorine dioxide and two types of tower systems for bleaching with chlorine dioxide.

CORROSION

Fitzsimmons (*183*) presents brief summaries of talks presented at a meeting of the National Association of Corrosion Engineers in Vancouver, B. C.

Stockman and Tansen (*184*) exposed five grades of steel used in evaporator tubes to the corrosive effects of black liquor and condensing black liquor vapors. Rimmed and killed carbon steels behaved alike. The 5% nickel steel suffered 40% less vapor-phase corrosion than did the carbon steels, but its superiority in the liquid phase was apparent only at higher sulfide contents. The stainless and the 13% chromium steel were highly resistant to corrosion in both phases. Venemark (*185*) found that, in a black liquor evaporation installation, marked corrosion of carbon steel occurred only at temperatures above 115°C. and liquor concentrations above 30%. Corrosion increased with temperature and was apparently proportional to the amount of dry solids in the liquor passing the steel surface.

Kesler (*186*) recalls earlier work on the corrosion of mild steel in kraft white liquor in which the prediction was made that a family of curves would be obtained by plotting liquor corrosivity against corrosion rate, each curve being specific for a definite sulfite ion concentration. Results of further work substantiate this prediction and further define the role of sulfite ion in steel corrosion in white liquor.

Stockman (*187*) studied the relationship between the corrosion rates of killed and rim steels in white liquor and the liquor's polysulfide content. The corrosion rate was found to be a nonlinear function of the polysulfide content and appeared to depend strongly on mass transport at the phase-boundary surface.

Harris and Park (*188*) report on experiences with sulfate digesters made of six different materials of construction. ASTM A 285 firebox steel is the best steel now available for sulfate digester construction. Bock (*189*) outlines the limits of application and special characteristics of rotary kraft digesters. Chromium-nickel-titanium alloy (Remanit 1880 ST) is adequate for making ordinary kraft paper pulps, whereas chromium-nickel-molybdenum-titanium alloy (Remanit 1810 SST) is recommended for high-quality rayon pulps.

Richter (*190*) obtained a patent which provides for reducing the corrosion rate of a digester by avoiding contact of the cooking liquor with the hot walls of the digester. This is accomplished by changing the charging procedure and by cooling the digester down before introducing the liquor.

Hopper (*191*) reviews a panel discussion covering the history of the overlay as a means of repairing alkaline digesters, installation methods, metallurgical problem involved, and experiences with the service life of the overlay. A patent was awarded to Mueller (*192*) for a method of inhibiting the corrosion of steel digesters by alkaline pulping liquors which comprises the installation of a cathode electrically insulated from the walls of the digester, and one or two rectifier units to maintain an electric current flow between the cathode and the walls of the digester. In this manner, the steel surface can be kept in a passive state and will prevent its activation by a fresh charge of white liquor.

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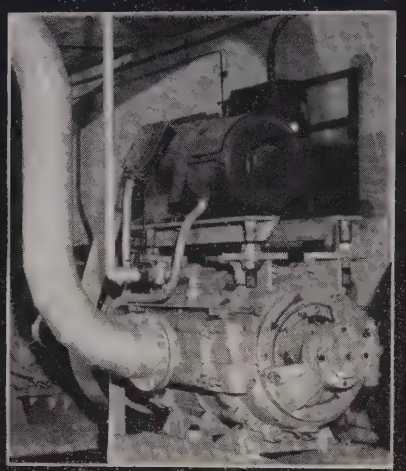

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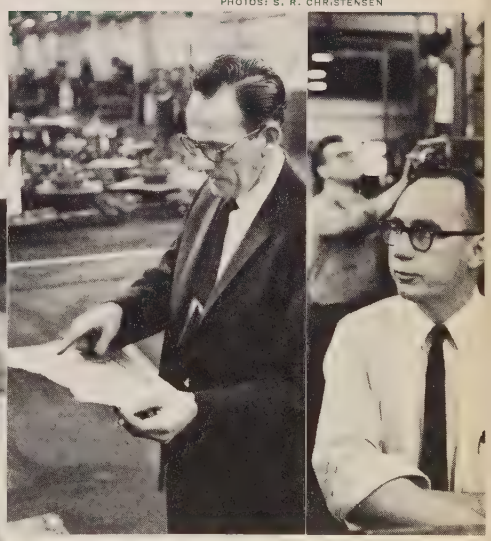

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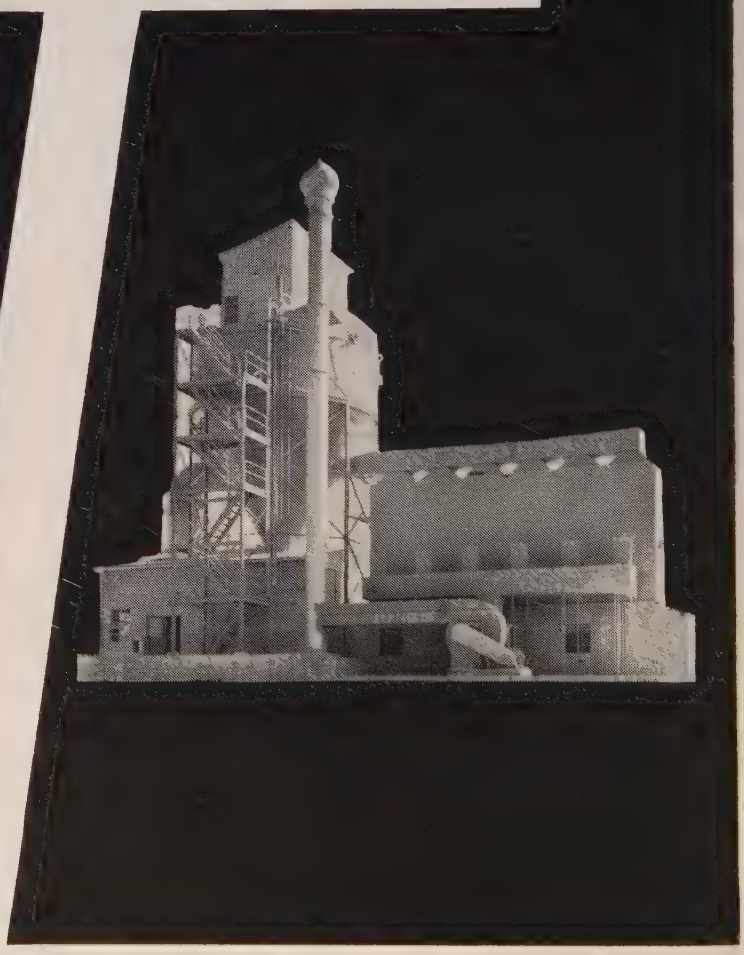

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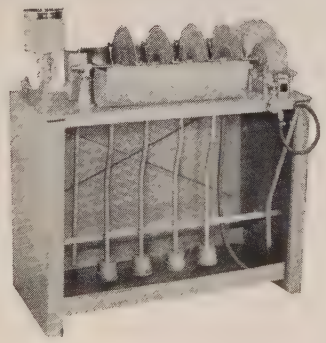

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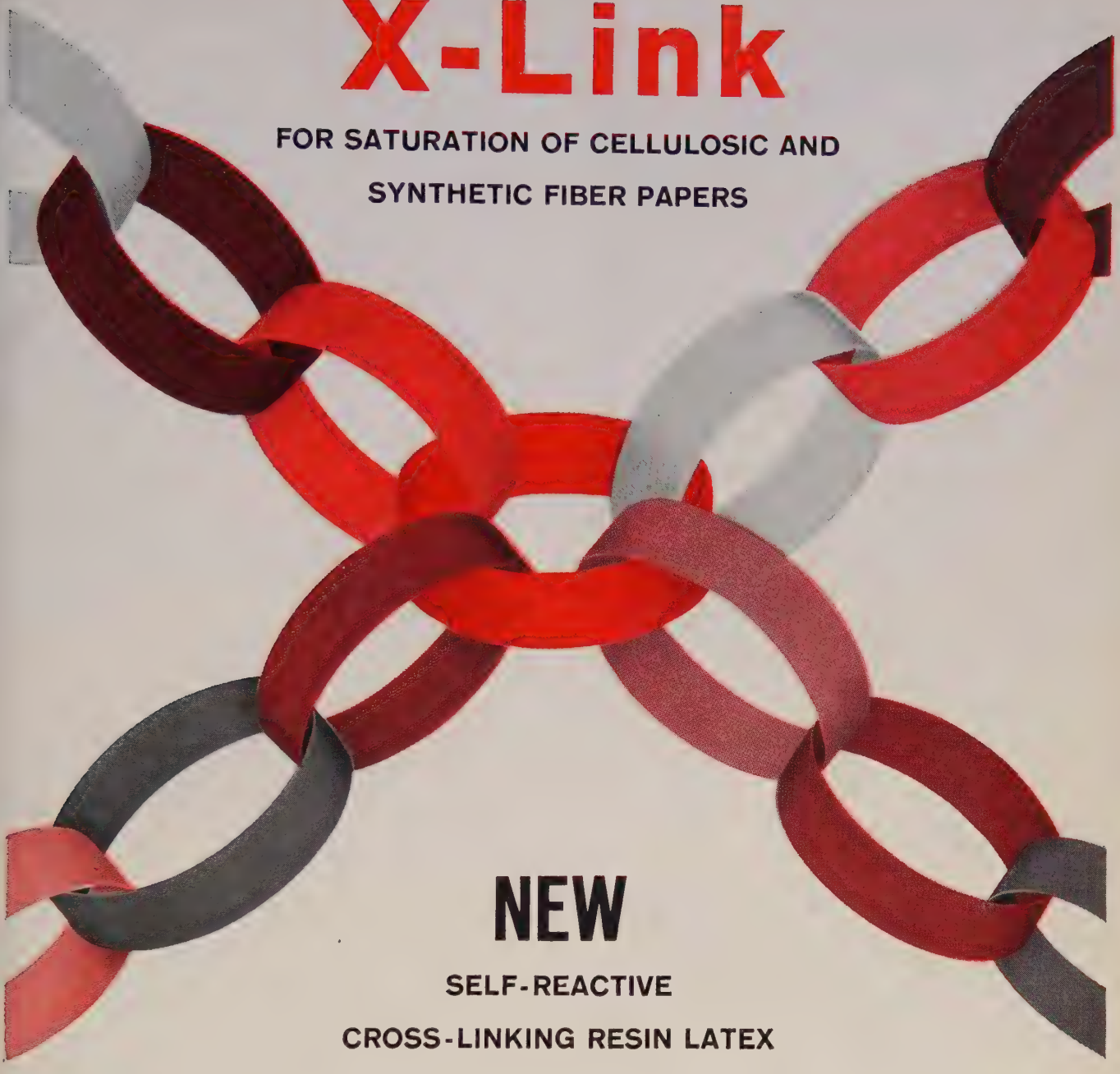

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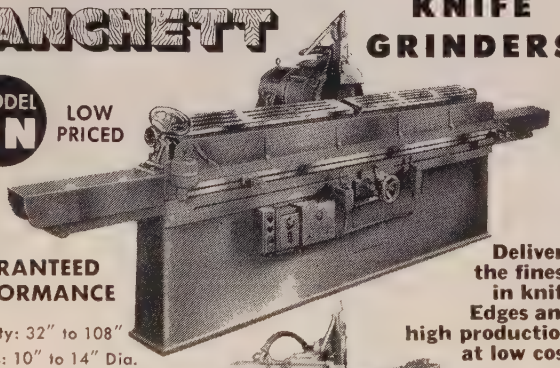

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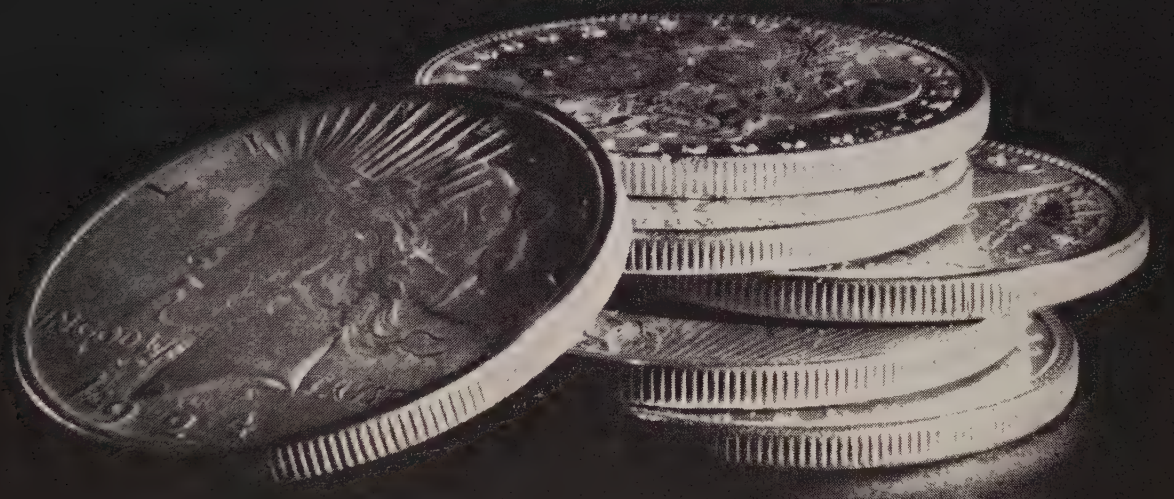
Another example of "Virginia" nationwide technical service

THIS STILL BLEACHES A TON OF PULP



A paper pulp mill recently took us up on our claim that single-stage pulp bleaching can be done with zinc hydro for $6 a ton at tops, including chemicals and steam. A few months later we got an indignant complaint. Costs were running well above $6. We checked our records. The mill's purchases of hydro seemed high. We sent a technical service man around on the run, and he found the answer fast. The operator, overlooking the importance of air-free mixing, was simply dumping the zinc hydro upon the pulp. Though more stable than sodium hydro when exposed to air, the zinc hydro was degrading far too rapidly under this careless handling. The "Virginia" man showed the operator how to prepare the bleach solution properly, how to add it to the pulp slurry as close to the agitator as possible to get quick, thorough, air-free mixing. A check of the bleached stock retention chests at the end of the reaction time showed the pulp to be at the proper brightness level. Consumption of zinc hydro—normal. Cost—down to well below the conservative $6 per ton we had claimed. For more information on bleaching with hydro—or to arrange for a free mill trial—write, phone or wire Chemical Division, VIRGINIA CHEMICALS & SMELTING COMPANY, Dept. 313, West Norfolk, Va.

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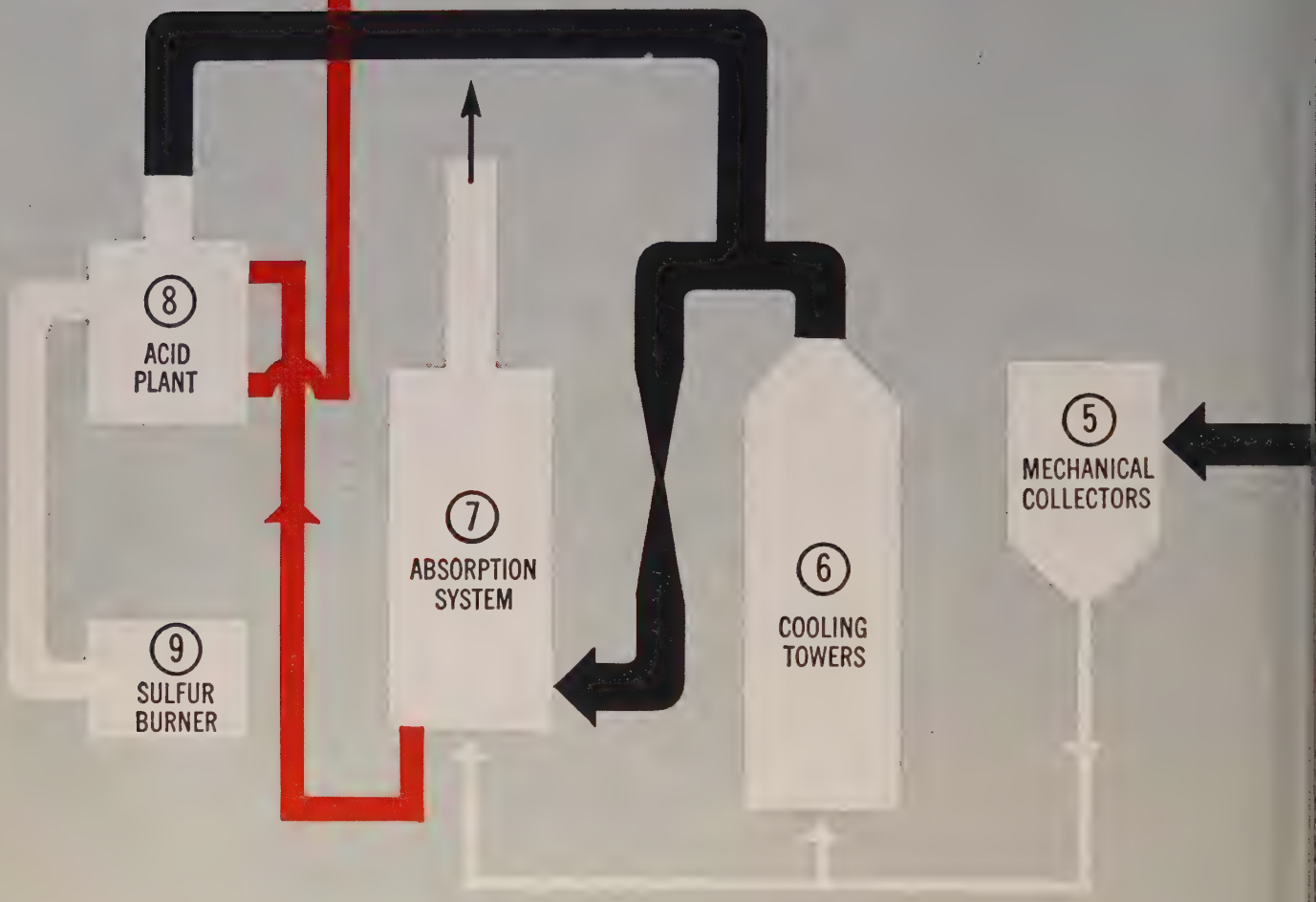
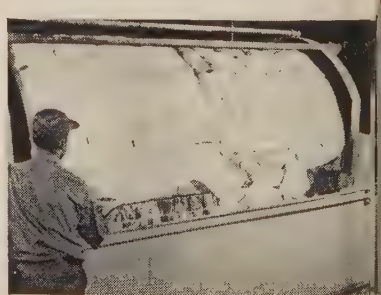
MgO pulping and recovery process. Pulp wood chips are digested in magnesium bisulfite liquor (1) pulp is withdrawn and washed (2) and knots removed. Liquor with 10 to 15% solids is passed through multiple-effect evaporators (3) to raise the solids content to 55% before burning in recovery boilers (4) to produce steam at 860 psi and 825 F for power generation and processing. MgO and SO_2 are released from the liquor during the incineration process. MgO is recovered in mechanical collectors (5) while the SO_2 and flue gases pass to the cooling and absorption towers (6). Recovered MgO is hydrated and introduced into the acid circulating to the absorption system (7). Here it combines with SO_2 to form magnesium bisulfite acid. The cycle is completed by fortifying the recovered magnesium bisulfite acid (8) with sulfur dioxide from the sulfur burner (9).



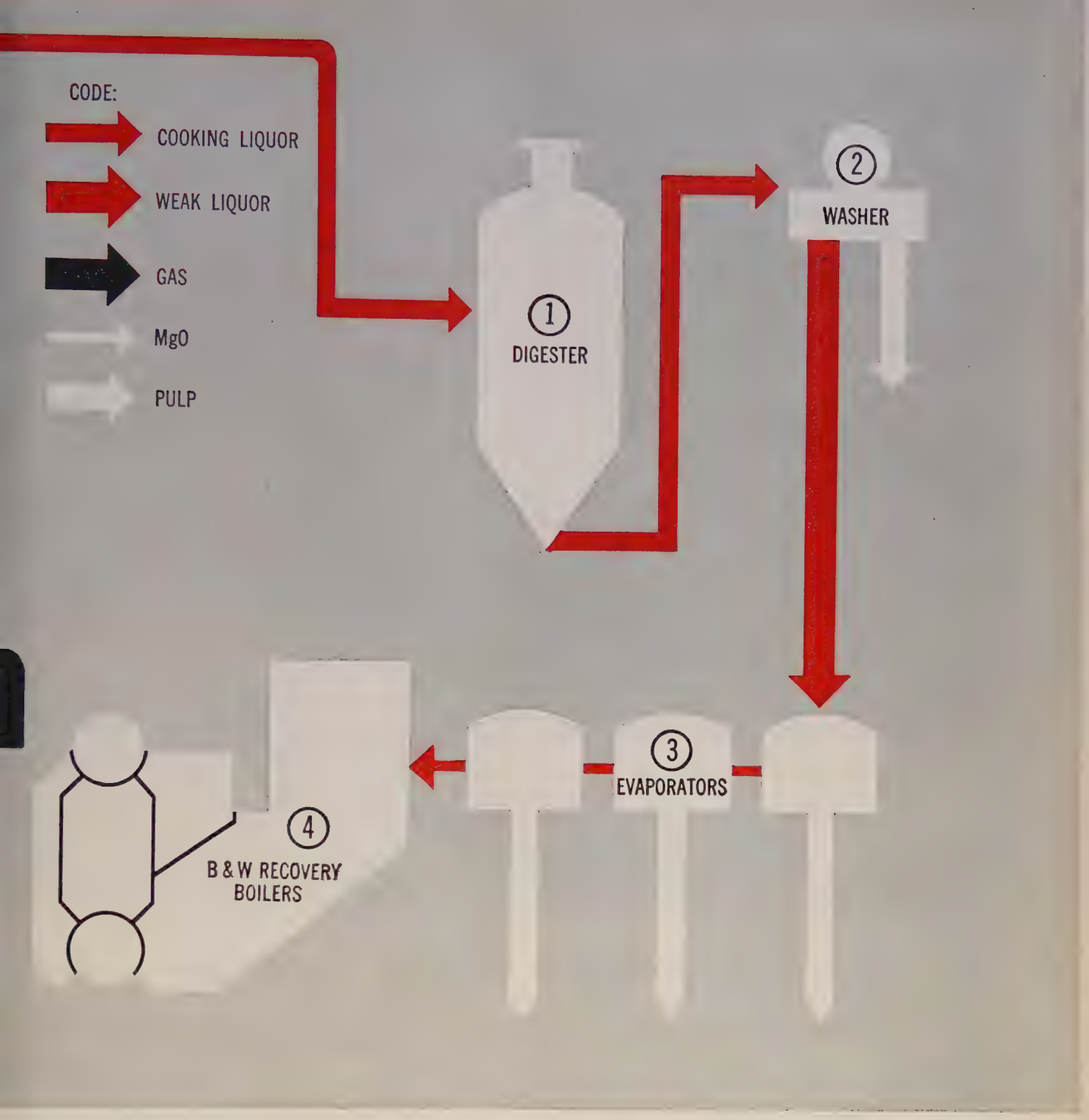
MgO process at Weyerhaeuser's Cosmopo

Evaporators in series increase pulping liquor from less than 15% to about 55% solids to permit its burning.

B&W MgO recovery boilers burn the concentrated liquor, supplying 70% of the plant's steam requirements.



Mechanical collector reclaims Mg(from furnace flue gas and washes before further use.



l recovers 90% of spent liquor solids

y 20 pounds of magnesium oxide 40 pounds of sulfur per ton of bleached pulp are needed for ke-up at Weyerhaeuser Com-y's 400 ton per day sulfite mill at mopolis, Washington.

he simple, closed cycle MgO ping and recovery process, ed in operation during 1957, re-ms about 90% of the pulping nicals. The B&W MgO recovery ers provide 70% of the steam required for the entire plant's power generation and processing needs. A third B&W bark and oil fired boiler provides the balance of steam requirements.

The commercially-proven MgO pulping and recovery process is ideal for either new mills or conversion and modernization of existing mills. Shorter cooking time required for MgO pulping cuts capital and maintenance costs in new installations and permits increasing the production of existing mills. Quality sulfite pulp with high brightness and strength is produced.

For more information about the efficient MgO pulping and recovery process, contact your nearest B&W sales office or write The Babcock & Wilcox Company, Boiler Division, Barberton, Ohio. E-302-1001

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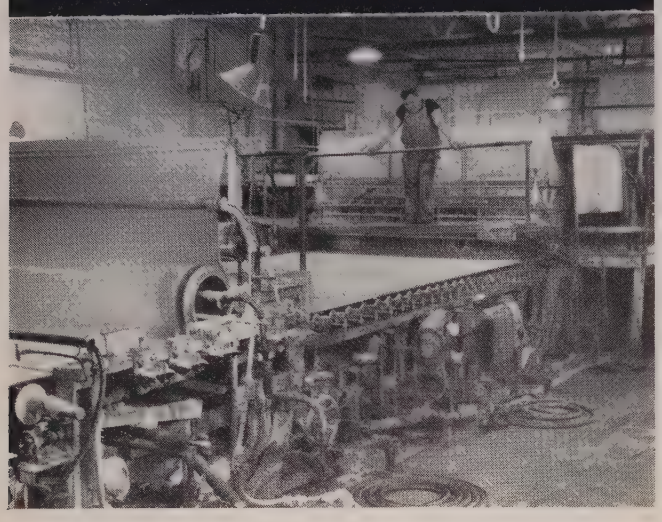
3 WAYS PQ SILICATES reduce paper making costs



can you use one or all?

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2 The use of activated silica sol in the headbox increases retention of fines and filler on the wire, thus the quality is improved with a uniformly smooth closed sheet.

3 Re-use white water from the paper machine by clarifying with activated silica*. This enmeshes clay and fiber content; white water solids are reduced to ¼ lb. or less, per 1000 gallons.

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*Prepared with our N sodium silicate and a reacting chemical in your mill.

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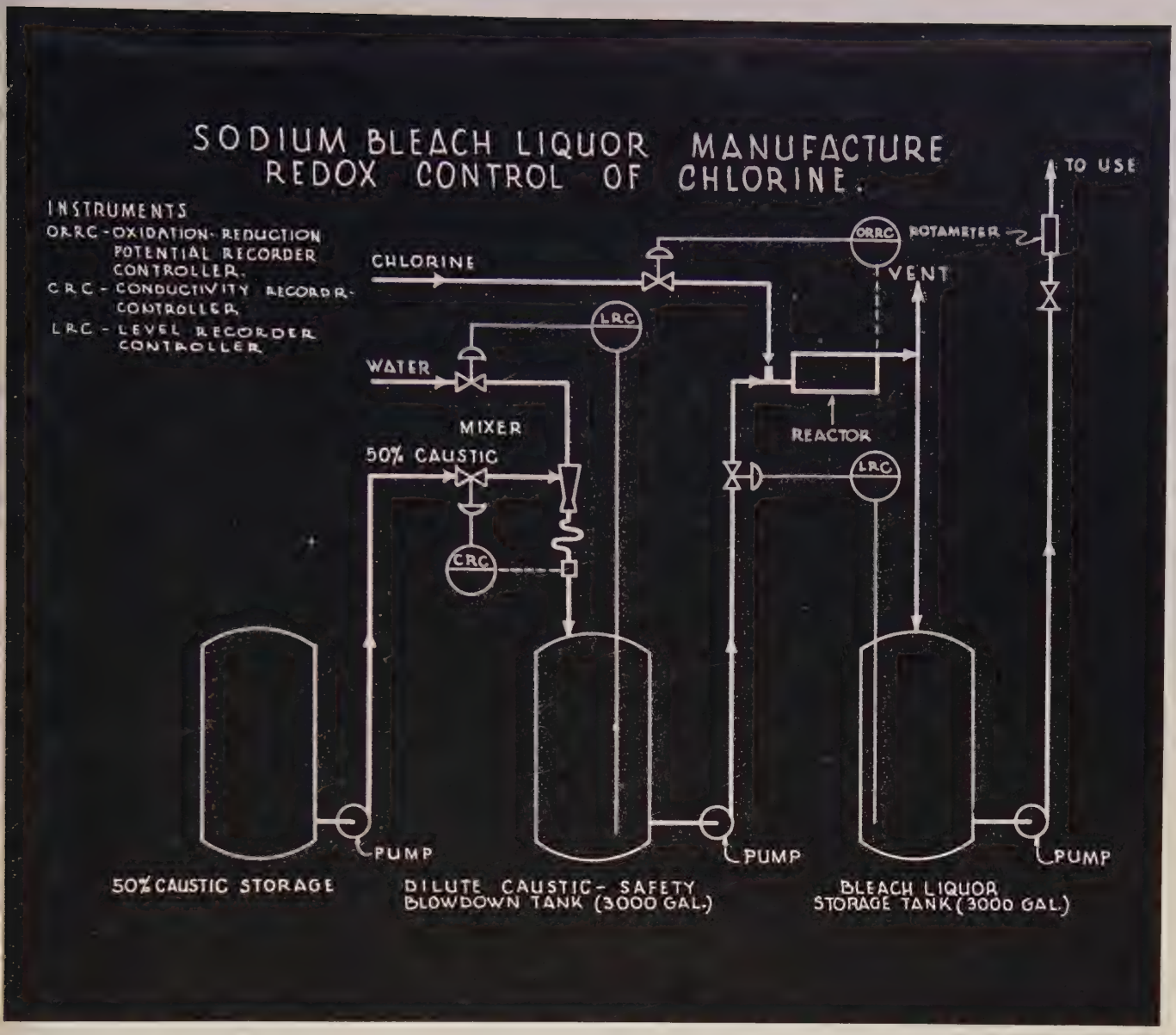

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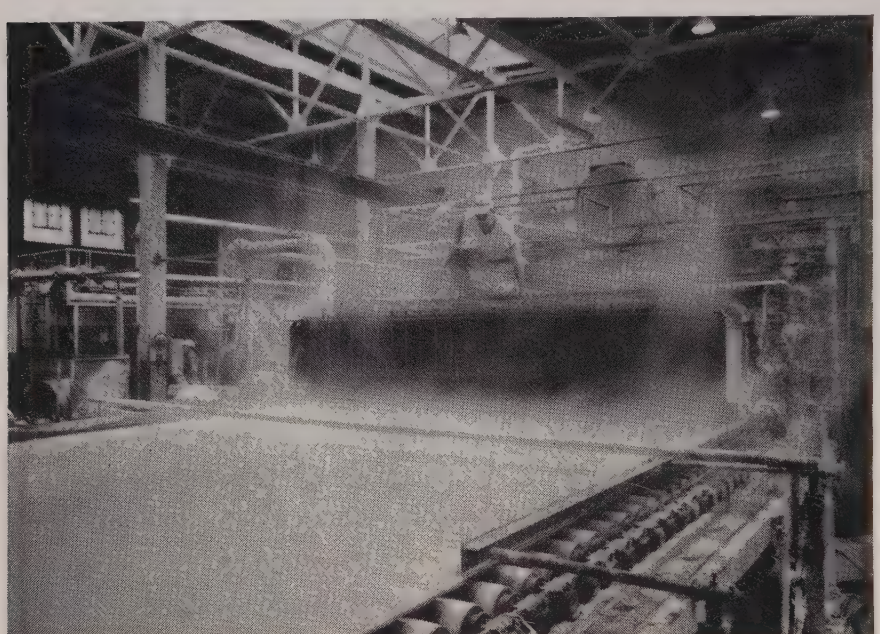

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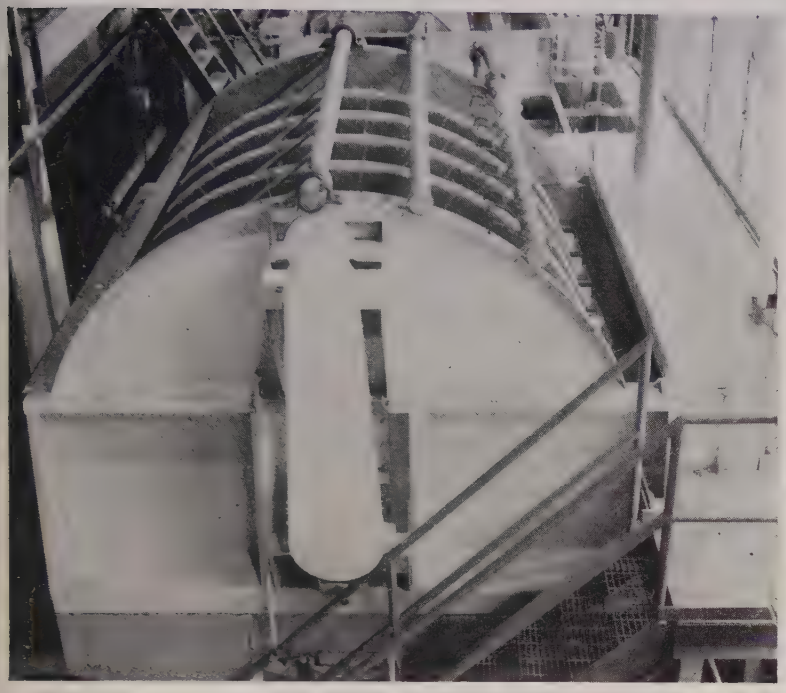


Molded Discs and One-piece Stainless Core Raise Capacity and Clarity Standards — Due to New Hydrodynamic Design Concept.

Close up your white water system with the new Impco Disc Filter! This saveall concept, with its molded sectors and one-piece stainless core, is a fresh approach to disc type filtering. Hydrodynamic design and latest materials now give you a truly ultramodern filter.

Swept back, molded, lightweight, bonded-face sectors increase capacity and wire life. Contra-flow inlet eliminates pulp thickening in vat. Eighteen ported trunnion and full 180° valve opening produce sharpest filtrate separations. Speeds from ¾ to 4.5 R.P.M. Ask your Impco Sales Engineer for full information and write for Bulletin A5-1.

Above: Six-disc unit minus vat, showing valve and dual filtrate discharge. Filters available in sizes up to sixteen discs. Keyed aligning and attaching device makes assembly of a complete disc the simplest yet. A complete disc consisting of eighteen 22 pound sectors is assembled in one hour.

IMPROVED MACHINERY INC. NASHUA, NEW HAMPSHIRE

IMPCO®

IN CANADA: Sherbrooke Machineries Limited, Sherbrooke, Quebec

DOW

pulp processing chemicals

MAGNESIUM HYDROXIDE SLURRY

MAGNEFITE PULPING GIVES HIGHER STRENGTH AND YIELDS, SHORTER COOKS, THROUGH A WIDER RANGE OF WOODS

A significant improvement over earlier magnesium-base pulping process, the Magnefite process permits a greater range of wood species to be pulped . . . in shorter cooking cycles . . . producing excellent pulp at higher strength and brightness with better yields. Magnefite pulping may be combined with a highly efficient commercially proven heat and chemical recovery process.

The Magnefite process has been successfully applied to a wide variety of woods—jack pine, tamarack, white pine, birch, elm, poplar, maple, and other difficult-to-process woods—permitting a lower cost/ton of pulp produced.

Processing advantages are numerous. Cooking cycles are shorter since there is no limit to the speed at which the temperature of the digester can be raised. The absence of large quantities of SO_2 gas in the digester permits cooking at higher temperatures. A rapid increase in temperature is also possible as a result of impregnating pulpwood chips with hot magnesium bisulfite liquor of equal combined and free SO_2. With such rapid penetration of chips, cooking time is reduced as much as 40%! This results in a substantial increase in digester capacity. The absence of true free SO_2 simplifies liquor make-up, eliminates the need for pressure storage vessels, and practically does away with dry relief.

In some cases, the cost and processing advantages of Magnefite pulping justify its use even without chemical recovery. Where chemical recovery is justified, 90 percent of the pulping chemicals may be reclaimed and reconstituted in a recovery system.

Dow is a basic supplier of the principal ingredient, magnesium hydroxide . . . in slurry form for maximum handling ease . . . available for immediate delivery. Chances are Magnefite pulping can be an advantage in your processing operation. Write THE DOW CHEMICAL COMPANY, Midland, Michigan, Chemicals Sales Department 802FC8, for further details.

THIRTEEN LOCATIONS COUNTRY-WIDE ASSURE PROMPT DELIVERY OF DOW CAUSTIC SODA

To serve you better, Dow Caustic Soda Solution 50% is available when, where, and how you want it from thirteen shipping points throughout the country. Fast delivery is assured via tank car and tank truck from four producing plants—Midland, Mich.; Freeport, Texas; Plaquemine, La.; and Pittsburg, Calif.; plus nine terminals—N. Charleston, S. C.; Carteret and Bayonne, N. J.; Denver, Colo.; Grants, N. Mex.; Chicago, Ill.; Los Angeles, Calif.; St. Louis, Mo., and Baltimore, Md. All provide tank truck and tank car shipments. For more information, call your nearest Dow Sales Office or write THE DOW CHEMICAL COMPANY, Midland, Michigan.

THE DOW CHEMICAL COMPANY DOW Midland, Michigan

You won't want to miss the . . .

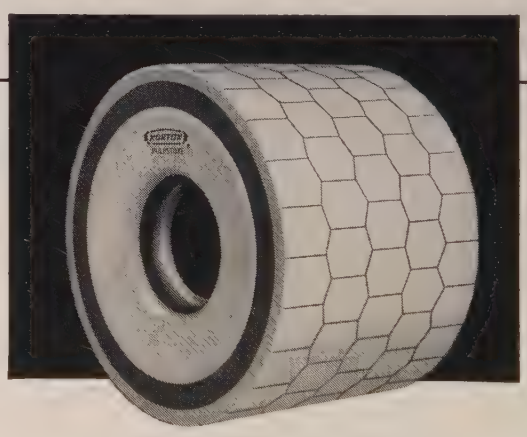
4th International MECHANICAL PULPING CONFERENCE

Edgewater Beach Hotel · Chicago, Illinois, U.S.A.
September 19, 20 and 21, 1961

Norton personnel from all over the world will be there to discuss the latest developments and techniques such as pitless grinding, higher speeds, and in general, how to get the most out of your present equipment.

This conference, jointly sponsored by the Technical Association of the Pulp & Paper Industry, and the Technical Section — Canadian Pulp & Paper Association, will again feature formal papers, round table discussions and new ideas on the production of mechanical pulp.

For the fourth time, a broad range of topics has been selected with authorities from Canada, Germany, Italy and Sweden, among others, scheduled as speakers.



Constant research enables Norton Company to anticipate and meet the requirements of every pulp and paper mill; one of the many reasons why Norton pulpstones are the world's standard for mechanical pulp.

NORTON COMPANY, WORCESTER 6, MASS.
Norton Company of Canada Ltd., Hamilton, Ont.
Norton International Inc., Worcester 6, Mass.

NORTON PULPSTONES — *the world's standard for mechanical pulp*

Making better products . . . to make your products better

NORTON PRODUCTS: Abrasives • Grinding Wheels • Grinding Machines • Refractories • Electro-Chemicals — BEHR-MANNING DIVISION: Coated Abrasives • Sharpening Stones • Pressure-Sensitive Tapes

Quality YOU CAN SEE...

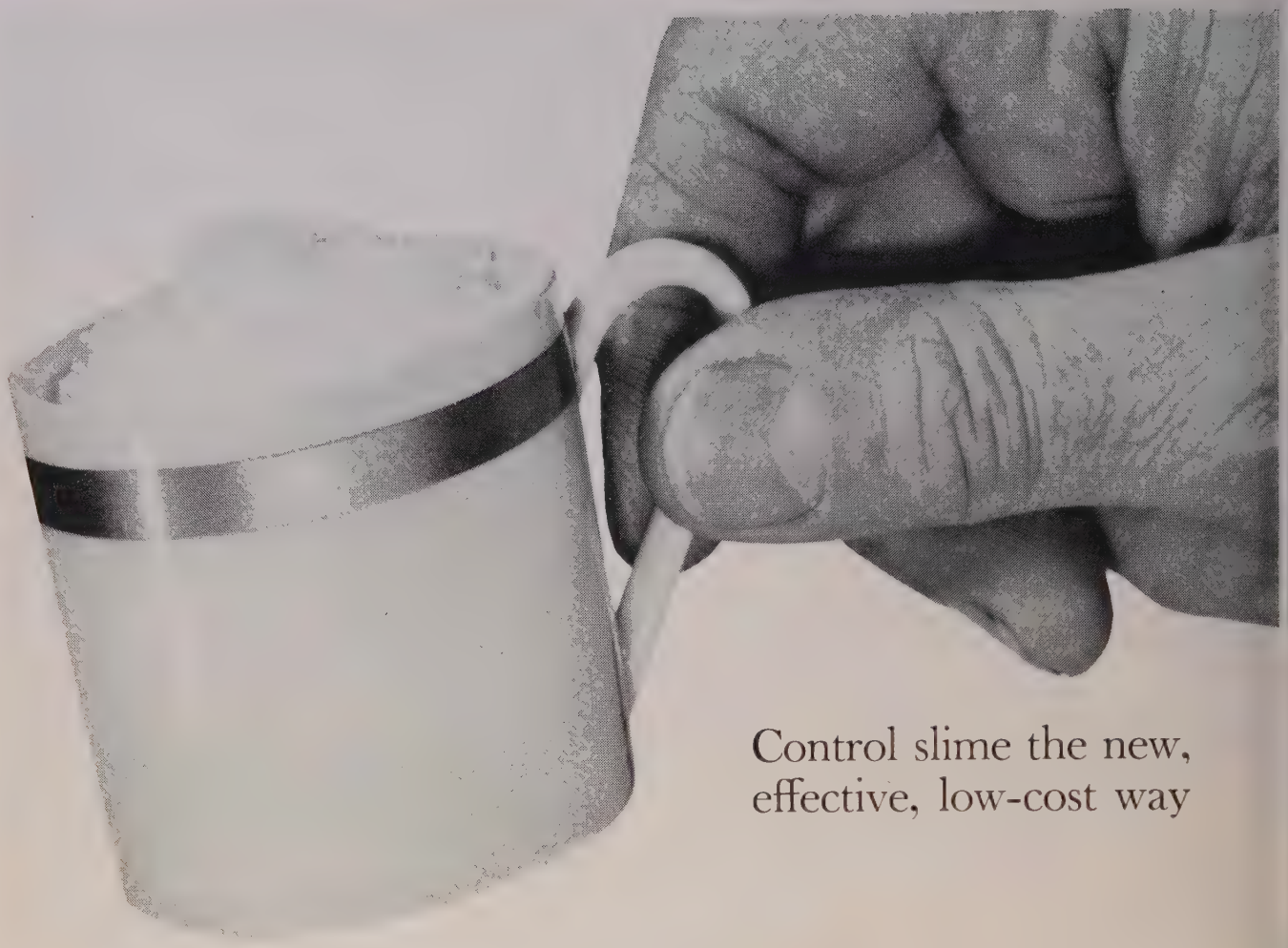
When you look through a speeding roll of carbon paper, the slightest defect in the wax used will show up quickly. Wax, the vehicle for the ink, is the essential ingredient in the ultra-thin carbon paper made by the Kling Manufacturing Company, of Chicago. Their customers, manufacturers of "unit sets," insist on high quality.

Eight years ago Kling chose Cities Service Pacemaker 53 Wax. Because they compete with larger national companies, they must offer their customers superior quality and fast service. "You can see," says Plant Superintendent Frank Orlow, "that our quality control is a direct result of the wax we use."

If you want to see a quality wax in action, try Pacemaker 53 Wax. Call your nearest Cities Service office or write: Cities Service Oil Company, 60 Wall Street, New York 5, N. Y.

CITIES SERVICE

QUALITY PETROLEUM PRODUCTS



Control slime the new, effective, low-cost way

Just this much C2® slimicide for a ton of pulp!

- Newsprint
- Unbleached, semi-bleached and bleached kraft
- Food and paper board
- Printing and book papers

EFFECTIVE. Extensive mill use proves conclusively that C2, the new Mathieson slimicide, is the most effective product for acidic white water systems. Only ¼ pound of C2 per ton of pulp (often even less) is a common dosage rate for rapid, sustained control. Actual cost per ton: about 10-20¢. Resultant action: continuous generation of chlorine dioxide throughout the white water system . . . a distinct advantage over other slimicides which function only near point of application.

Other C2 advantages: no foaming at the head box . . . will not darken pulp . . . will not affect dyes at recommended dosage rates.

EASY-TO-USE. C2 is readily soluble in water and is non-corrosive to equipment.

C2 is shipped in highly-soluble, dry-flake form in quantities from one-pound samples to 100-pound drums in truckloads and carloads. Also, 50% solution is supplied in tank cars and trucks.

FDA CLEARANCE. C2 is our trademark for sodium chlorite. The Food And Drug Administration has expressed the opinion that this chemical is not a food additive when used as a slimicide as it cannot reasonably be expected to become a component of food through this use.

See C2 work in your mill—call for a demonstration.

Olin Mathieson, Baltimore 3, Maryland

CHEMICALS DIVISION **Olin**

164

PHOTOGRAPHY BY GEORGE NORDHAUSEN

Checkmate forest fires

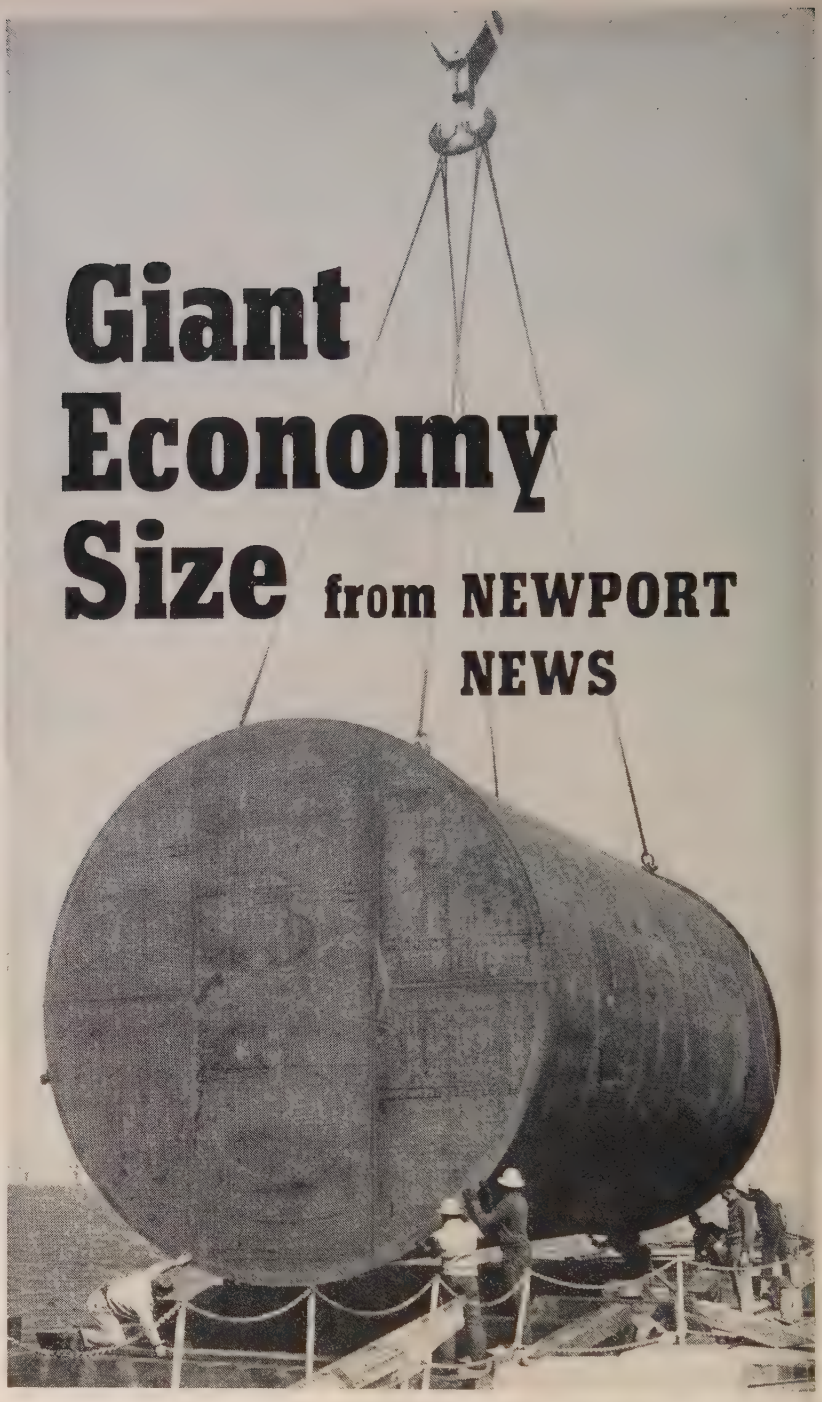
Fires ravage about five million acres
voodland and range annually in the United States.
Prevention is everybody's job!

Weyerhaeuser Company

Pulp and Paperboard Division

Why a Southern paper mill ordered the...

Giant Economy Size from NEWPORT NEWS



Nine more to go. You're looking at one of ten lime storage tanks being loaded on a barge for direct shipment from Newport News' plant. Complete assembly of these units in the shop not only saves labor and money but expedites installation upon arrival at the paper mill.

Papermakers usually encounter some perplexing problems when pressure vessels, digesters, tanks or similar large size units are involved.

For instance, a southern paper mill required ten lime storage tanks like the one pictured here. The size, 20 feet in diameter by 40 feet in length, obviously prohibited one-piece delivery by rail.

However, the mill found a way to eliminate field assembly problems and avoid needless labor costs, as well as to save valuable erection time . . . by handing the job to Newport News.

Specialists in metal fabrication, Newport News produced these tanks in the shop, then loaded them on barges for direct shipment, fully assembled, ready for immediate installation upon arrival.

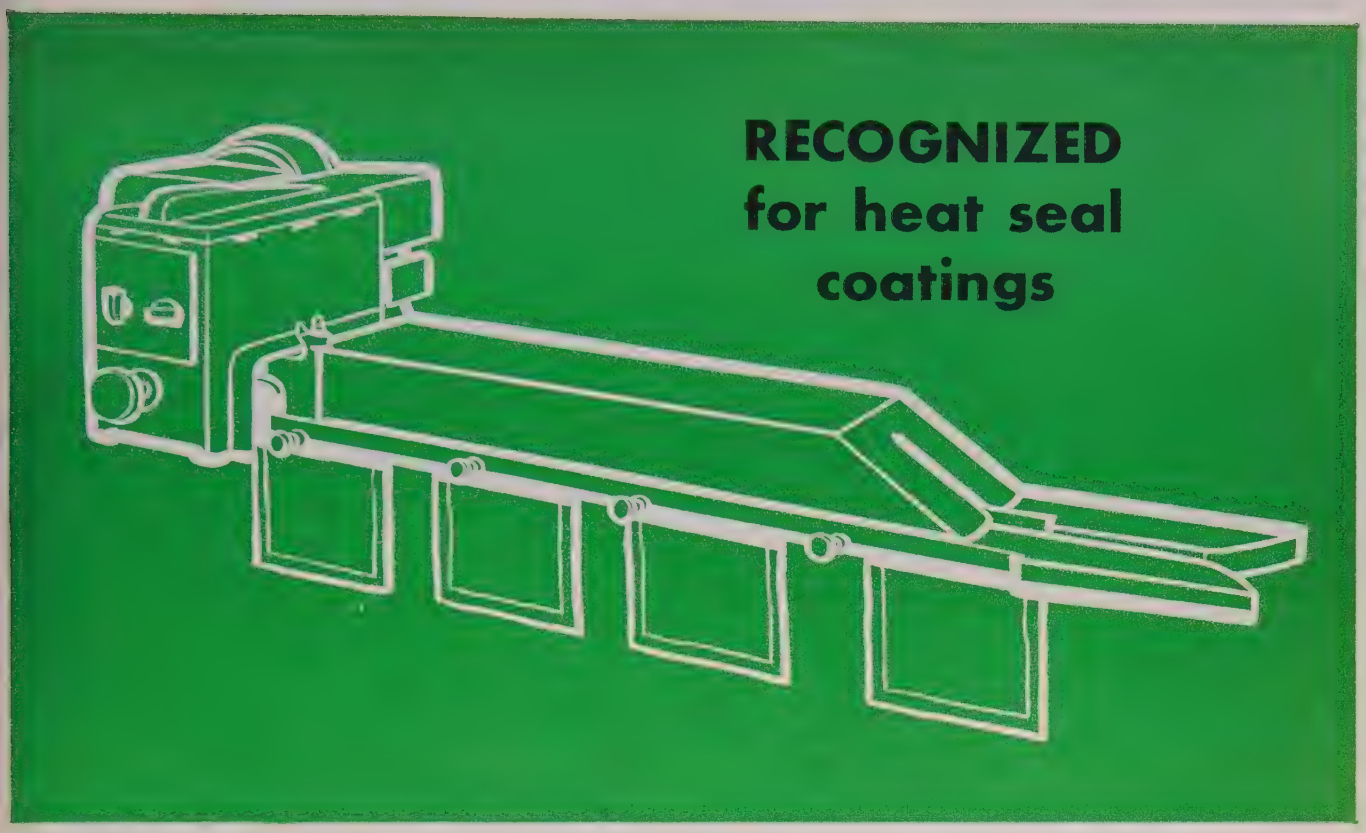
This illustrates how deep water shipping, along with sixty-seven years' experience in building just about any kind of vessel you could name, has enabled Newport News to provide money-saving answers for scores of papermakers.

Papermaking equipment built by Newport News has set outstanding performance records in leading mills at home and abroad. So whether you use *rolls or log barkers . . . head boxes or pressure vessels . . . digesters, tanks or special equipment . . .* let us bid on your needs. Learn how Newport News can help you . . . our illustrated booklet *"Facilities and Products"* is yours for the asking. Write for your copy today.

Newport News

Shipbuilding and Dry Dock Company

Newport News, Virginia



Gelva® polyvinyl acetate emulsions

GELVA EMULSION PROPERTIES CHART

Type	S-55 Homopolymer Dispersion	TS-22 Homopolymer Dispersion	TS-30 Homopolymer Dispersion	TS-70 Copolymer Dispersion	TS-85 Homopolymer Dispersion	TS-100 Copolymer Dispersion of Vinyl Acetate-Acrylate	C-3 Alkali Soluble Copolymer Dispersion
Total Solids (min.)	55%	55%	55%	55%	54.5%	54.5%	54.5%
Emulsion Viscosity, cps	1100-1300	350-650	1200-1400	900-1300	1400-1700	1000-2000	700-1000
Heat seal temp. of film, °F.	195-205	195-205	200-210	170-180	140-150	180-190	145-155
Mechanical Stability	Excellent	Good	Good	Good	Good	Good	Good
Freeze-Thaw Stability	Very Good	Good	Poor	Very Good	Very Good	Good	Poor

Whether it's a heat seal coating for glassine or for paper . . . or even vinyl chloride, there's a GELVA emulsion for your application.

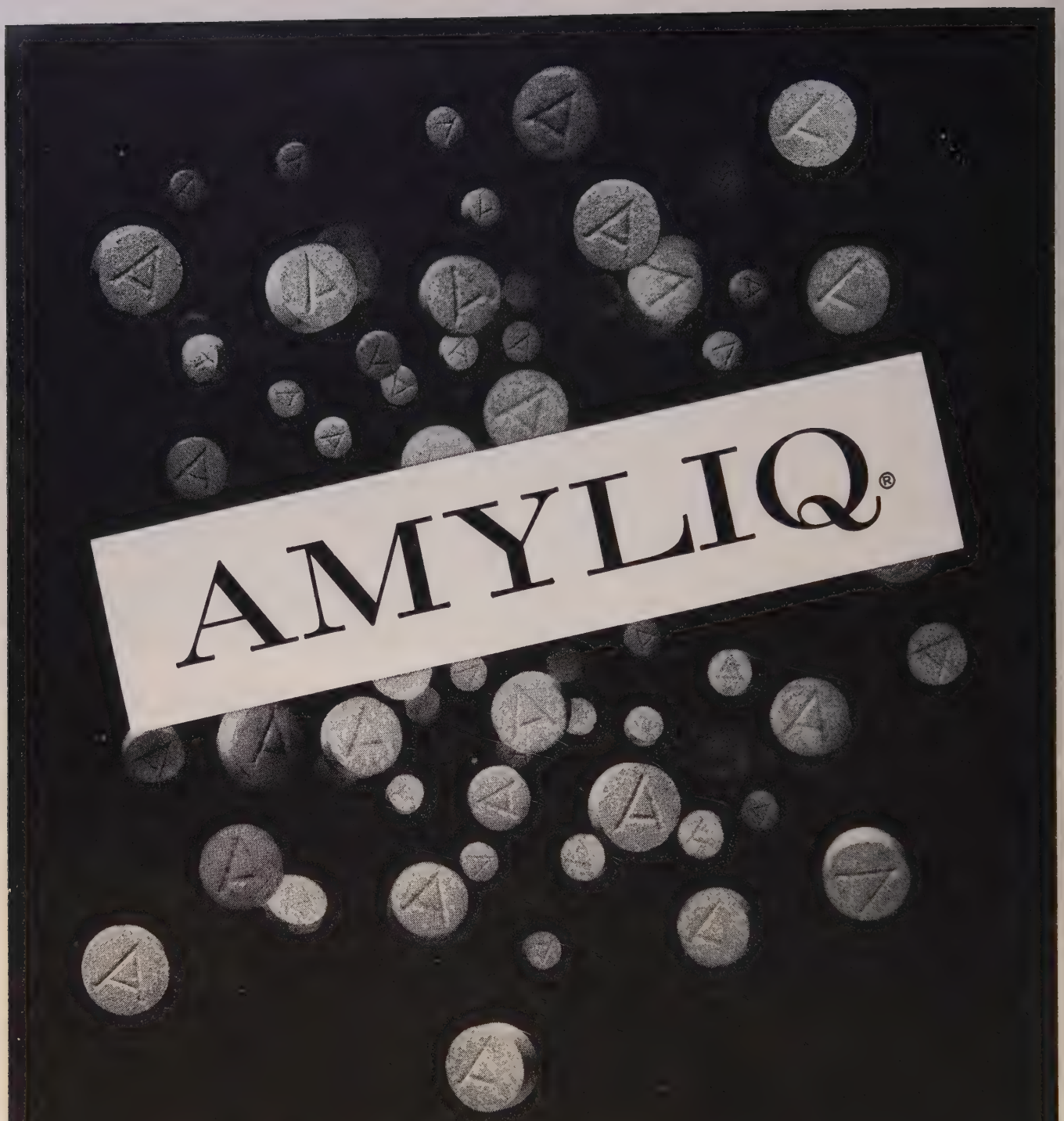
Excellent adhesion to a wide variety of surfaces, superior compounding stability and machining characteristics, wide solvent tolerance and high bond strength are a few of the important advantages of Shawinigan's GELVA emulsions. The above chart presents physical properties of GELVA emulsions suitable for compounding heat seal coatings.

GELVA emulsions are available in a wide variety of grades and in any desired quantity . . . ready for shipment. Whether you need emulsions for pigment bindings, coatings, sizings . . . stability to light sensitive salts . . . water resistant coatings or molded pulp — you can get complete details by writing Shawinigan Resins Corporation, Dept. SG Springfield 1, Massachusetts.

SALES OFFICES: ATLANTA CHICAGO LOS ANGELES NEW YORK CLEVELAND SAN FRANCISCO GREENSBORO SPRINGFIELD ST. LOUIS

GELVA® *polyvinyl acetate resins by*

SHAWINIGAN RESINS



For Starch Conversion...

The α-amylase for the paper industry...available as AMYLIQ Super and AMYLIQ Concentrated bulk powders - and as AMYLIQ tablets, readily soluble preweighed units costing no more than powder.

For broke recovery: **SERIZYME®** liquid proteolytic enzyme

WALLERSTEIN COMPANY Division of Baxter Laboratories, Inc.
Wallerstein Square, Mariners Harbor, Staten Island 3, N.Y.

FLUIDICS* AT WORK

New way to fight corrosion... a PLASTIC coating from Pfaudler

Here's an economical way to protect your equipment from the corrosive effects of direct product contact and ambient corrosive atmospheres.

It's a new plastic coating called Pfaudlon® 301. A Pfaudler-developed water suspension of Hercules Penton,† it is sprayed on and then fired to a base metal.

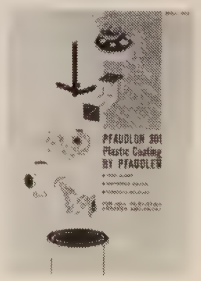
The resultant coating is hard, nonporous, glossy and smooth. It resists most corrosives to 210° F and is particularly well suited for use with the following acids: acetic (mixtures), chromic, hydrochloric, hydrofluoric, monochloroacetic, nitric (mixtures), and sulfuric.

Choice of metals. Pfaudlon 301 can be readily applied as an interior or exterior coating to such metals as mild steel, cast iron, stainless steels, Hastelloys, brass, bronze and copper.

Variety of equipment. Since this is a spray-type coating, complex shapes present no problem. So, you can use Pfaudlon 301's corrosion resistance in many kinds of equipment—storage tanks, open vessels, pumps and pump parts, hoods, blowers, ducts and baskets, to name a few.

Use it two ways. You can specify Pfaudlon 301 coating when you order new equipment fabricated by Pfaudler.® Or you can extend the service life of existing equipment by having it custom coated. Ten firms throughout the country are licensed by us to do custom coating.

Send for this booklet which gives complete details about this new plastic coating—what it is, recommended services, how applied, who can do it. That's Bulletin 1007, *Pfaudlon Plastic Coating by Pfaudler.* Write to Pfaudler Division, Dept. TA-81, Rochester 3, New York.



†Registered trademark for chlorinated polyether manufactured by Hercules Powder Company.

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes

*FLUIDICS is the Pfaudler Permutit program that integrates knowledge, equipment and experience in solving problems involving fluids.

DICALITE®
TECHNICAL REPORT
DICALITE DEPARTMENT • GREAT LAKES CARBON CORPORATION • 612 SO. FLOWER ST., LOS ANGELES 17, CALIFORNIA

New Dicalite BULK-AID for Paper Products

TRADEMARK

Dicalite BULK-AID is a new development in inorganic fillers, with particle size range and distribution carefully controlled to give maximum bulking characteristics in paperboard and paper products. BULK-AID has the lowest apparent or bulk density of any known mineral filler for papermaking use, thus providing required caliper at lower weights. One example is that of a 40-point groundwood sheet whose weight was reduced from 29.2 lbs/ft^3 to 27.3 lbs/ft^3 by the addition of 10% BULK-AID.

The light weight and bulking characteristics of BULK-AID make it especially suitable for use in paperboard; its high brightness and excellent retention are also of considerable value. BULK-AID lowers the furnish cost and increases pulp mileage in top liners for patent white paperboards. Its brightness and opacity raise the quality of underliners at the same time it extends the furnish.

Dicalite BULK-AID is an amorphous mineral, technically an aluminum silicate, produced from a volcanic mineral known as perlite by a special process developed by Great Lakes Carbon Corporation. BULK-AID is inert, insoluble in water, acid or mild alkalies. It is grit-free, and exhibits no reaction with alum in sizing or with other papermaking chemicals. It is readily dispersed in any furnish, does not cause foam, and will not fill felts.

Among BULK-AID's physical characteristics are these:

Color: White
Average G.E. Brightness: 83

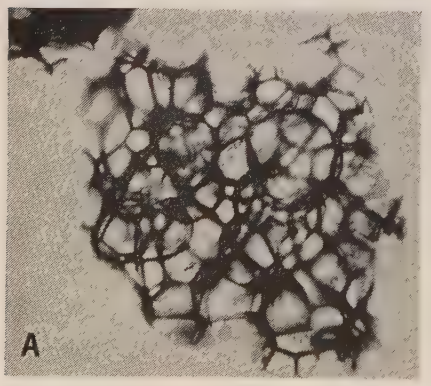
Loose weight: 4½ lbs/ft^3 average

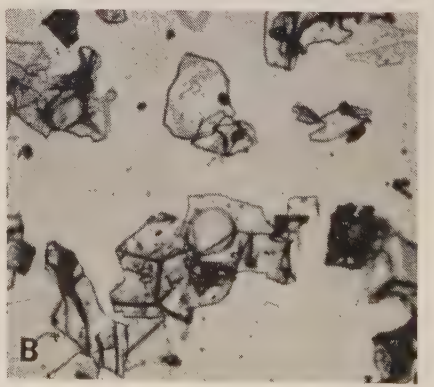
Bulk densities in paperboard: 15 lbs/ft^3 average.

Particle size: 80% less than 10 microns

Extensive testing has shown BULK-AID to be successful in actual paper mill production. Most of these tests were on cylinder machines for paperboard production, but limited tests indicate its value in many slow speed fourdrinier applications.

Your Dicalite engineer will be glad to discuss BULK-AID with you and to advise on possible product applications in your own plant.





When perlite is crushed and then suddenly heated to the proper point in its softening range, it pops like corn into particles like that shown in photomicrograph A, containing a myriad of microscopic sealed cells. The size of the original particle and the application of heat are both important, and are critically controlled. This is the expanded material from which BULK-AID is produced. Controlled milling and air classification by an exclusive Great Lakes Carbon Process are the major steps in making BULK-AID, typical particles of which are shown in photomicrograph B.

© 1961 GREAT LAKES CARBON CORPORATION • LOS ANGELES, CALIF.

Gordon G. Halvorsen

DICALITE'S "MAN ON THE SPOT"

The development of Bulk-Aid, to meet the industry's need for an extremely low density bulking agent, was initiated by Gordon Halvorsen, Product Sales Manager for Dicalite, and he has been closely identified with its tests and product application work from the beginning.

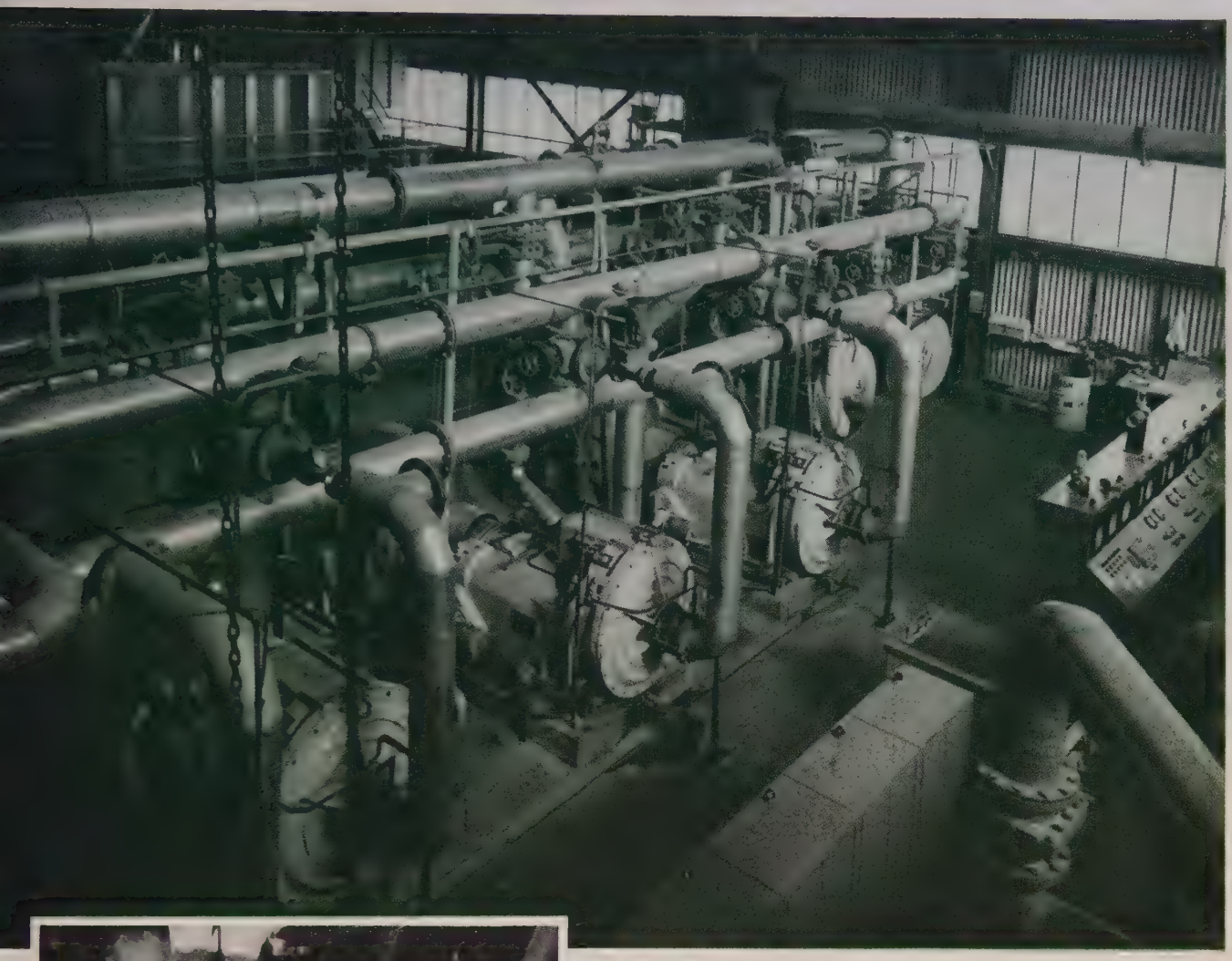
Halvorsen has an extensive background in research and development work, beginning with his graduation from the University of Minnesota with a degree in Chemical Engineering. Prior to joining Great Lakes Carbon in 1940, Gordon had been engaged in technical and laboratory work in the pharmaceutical, corn processing and water treatment fields, and continued his research work in the Dicalite product laboratories for the first 5 years of his association.

Halvorsen is the author of several technical papers, and has contributed to both paper industry and brewing publications. Among his technical society memberships he lists TAPPI, American Society of Sugar Beet Technologists, Master Brewers Association of America, and others in the brewing and drycleaning fields.

NEW DATA SHEET

on Dicalite *BULK-AID* gives more complete information on physical and chemical properties, and on its advantages in papermaking. Write for your copy to Dicalite Dept., 612 So. Flower St., Los Angeles 17, Calif.

23 YEAR DISC LIFE INDICATED



After two years of tough work Jones Double-D Super-Stainless discs show only .065″ wear — evenly distributed and with parallelism perfectly retained.

for Jones Double-D's on the Seminole Chief

Sept. 7, 1957 was the day St. Regis began to produce their fine quality Seminole Chief Board in Jacksonville — with the help of ten Jones Double-D's for both primary and secondary refining. Regular six month checks of the Jones Super Stainless discs in each Double-D show a maximum wear of only .0027″ per month. Applied against the available disc wear of .750″, this actually indicates a disc life of more than 23 years!

This fine record has been made, too, under heavy power requirements — normally more than 600 HP and sometimes running as high as 1000 HP on each primary refiner for periods of several weeks!

Have a tough refining problem? Better look into the Jones Double-D. Write to E. D. Jones Corporation, Pittsfield, Mass., for bulletin EDJ1083.

E. D. JONES CORP. member BELOIT group PITTSFIELD, MASS.

Jones

PULP MILL EQUIPMENT AND STOCK PREPARATION MACHINERY

Represented in Canada by
The Alexander Fleck Ltd.
75 Spencer Street, Ottawa

APPLETON WIRE WORKS, Corp.

Plants at Appleton, Wisconsin and Montgomery, Alabama.
International Wire Works, Menasha, Wisconsin,
an Affiliated Company.

V-10 now also in water soluble bags.

No need for a proportioning pump.

No expensive metering devices.

Makes accurate and clean addition of V-10 to control slime.

Vineland's V-10 . . . bis-1, 4-bromacetoxy-2, butene; a perfect slime controllant.

Proven* safe for any ordinary use in tissue, wadding and food board mills. Helps reduce downtime.

Vineland's technical staff is ready to assist you in establishing proper slime control in your mill. Bacterial counts and identification of prevalent microorganisms will be determined without cost or obligation.

Write or telephone (OX 1-3535) for free booklet, "Control of Slime in the Paper Mill."

* *Test results available on request.*

Vineland Chemical Co.

West Wheat Road, Vineland, New Jersey

NEW Sandy Hill

ROLL SPLITTER

LOWERS YOUR COSTS, SALVAGES CORE

Sandy Hill's new Roll Splitter gives you fast, clean splitting of reject paper rolls for repulping, and saves you money 3 ways:

1. No expensive hydraulic installation. Weight of blade assembly is all the pressure needed.

2. Little space needed for installation. No expe mill alterations required.

3. Operator can stop splitter before blade reaches giving you substantial savings on roll core salvage

For Complete Details and Specifications, WRITE

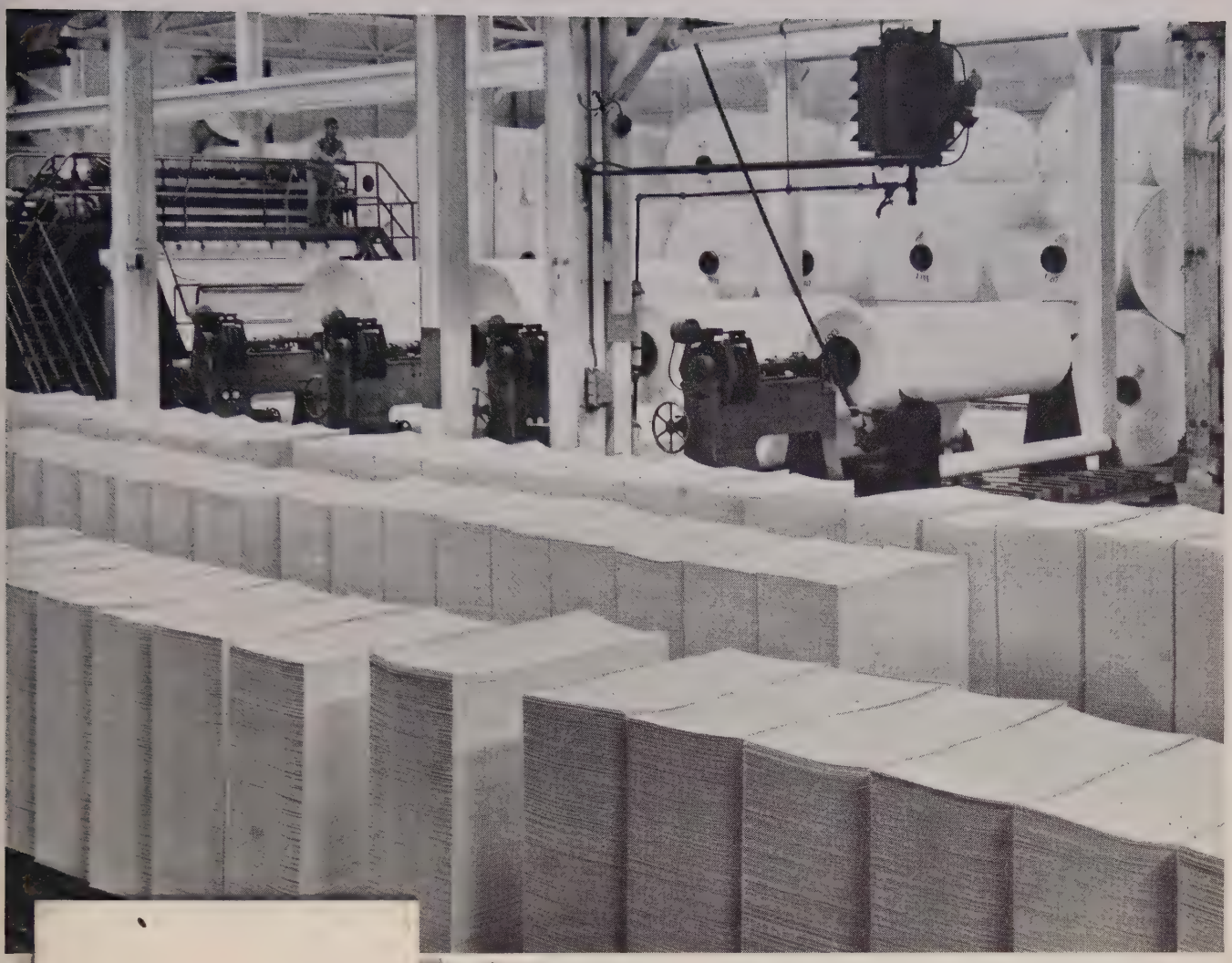
Patent Applied For

THE

SANDY HIL

IRON AND BRASS WOR

HUDSON FALLS, N. Y.



THIS IS GEORGIANIER

A bleached Kraft from southern pine, its high tear qualifies it admirably for quality paper products. Typical data on a Valley Test Beater at 30 minutes: Canadian Standard Freeness 530; Mullen Factor 116; Tear Factor 2.86; Fold Factor 12; Opacity 68.3%, G. E. Brightness 87.5%.

Write or telephone for your free samples and complete data.

product

Even though Rayonier produces the world's most complete line of pulps and constantly strives to anticipate your market requirements, there's no complacency at Rayonier about product superiority.

Instead we work to strengthen your competitive position with pulps of increasing qualities of strength, opacity, brightness and formation. For we have a long-term commitment with the paper industry: to supply you with the truly great pulps at realistic prices—like Georgianier, another rewarding opportunity for the papermaker.

For product excellence, start with excellence — a great Rayonier pulp!

RAYONIER
GREAT PAPER-MAKING PULPS

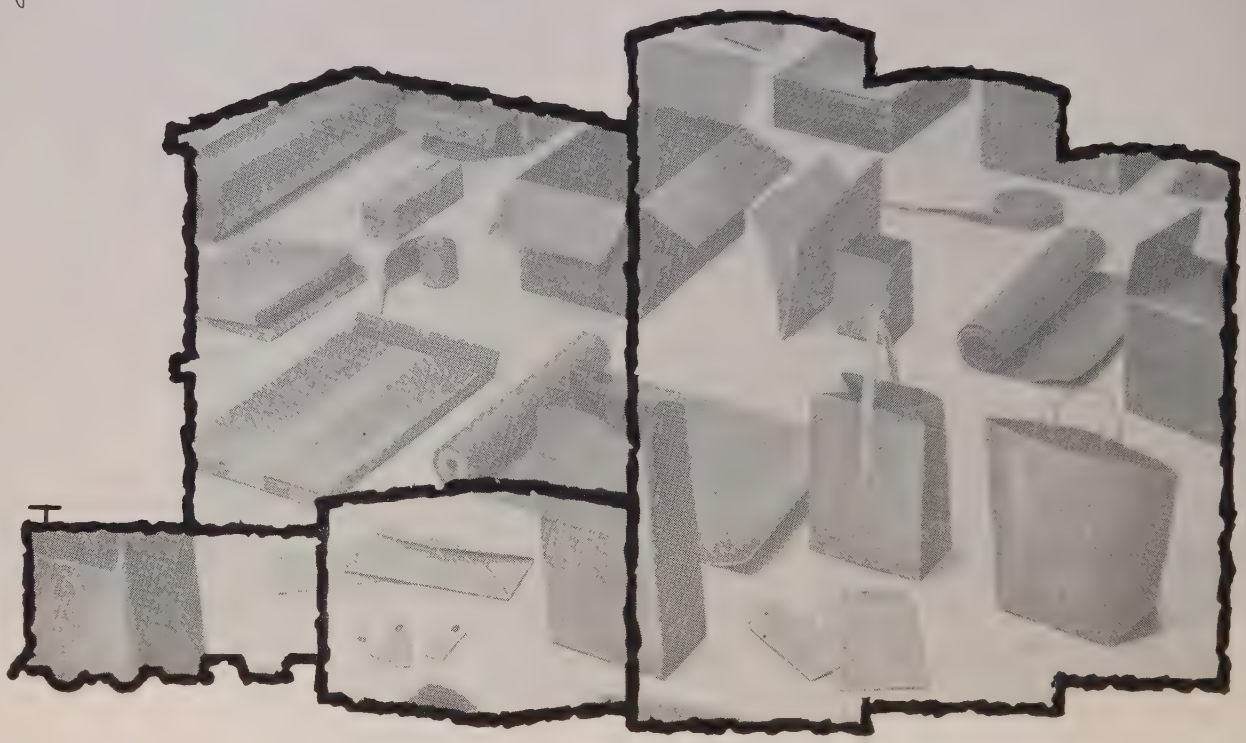
Rayonier Incorporated
161 East 42nd Street
New York 17, New York

World's Most Complete Line of Paper-Making Pulps: *Western hemlock bleached sulfites; western softwood bleached sulfates; western red cedar bleached sulfates; southern pine bleached sulfates; southern hardwood bleached sulfates; southern pine bleached sulfites.*

WEST END

advance planning

OF EXPANDED SALT CAKE PRODUCTION ANTICIPATES INDUSTRY'S GROWING NEEDS

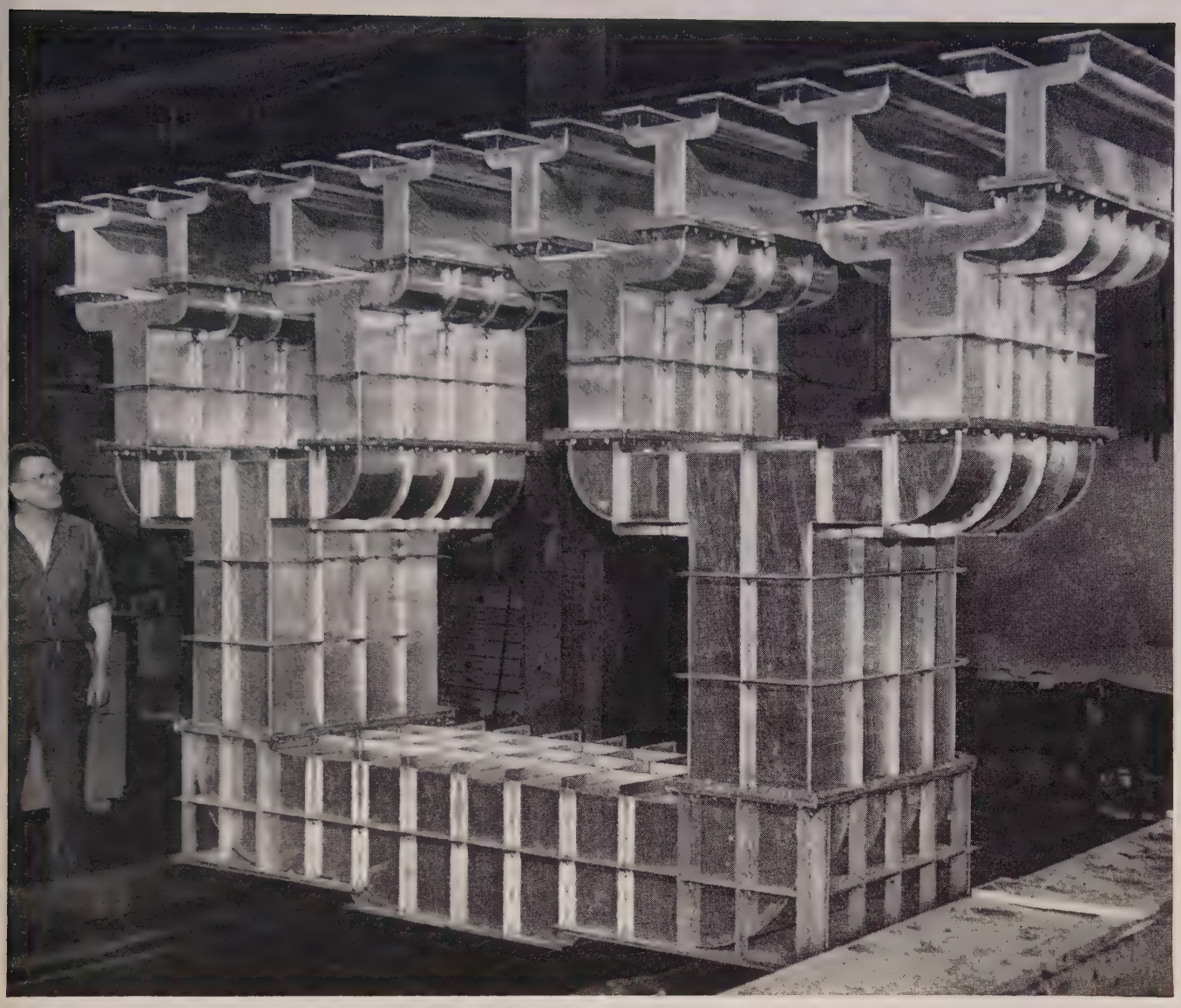


WEST END demonstrates its complete reliability as a major source by the continuing enlargement of its production facilities devoted to the manufacture of highest quality salt cake as a prime product. Independent of other product production and located at the site of vast natural raw material supply, West End is solidly qualified to handle the complete requirements of customers dependably, economically and efficiently.

Stauffer CHEMICALS

WEST END CHEMICAL COMPANY • DIVISION OF STAUFFER CHEMICAL COMPAN

636 CALIFORNIA STREET, SAN FRANCISCO, CALIFORNIA • PLANT: WESTEND, CALIFORNI



This Fourdrinier flow distributor, weighing 8 tons, shows...

how Nickel Stainless Steel equipment keeps paper production up—production losses down

When the engineers at Sandy Hill Iron and Brass Works tackled the job of fabricating this Fourdrinier flow distributor, they were well aware that failure of a piece of equipment like this could cost over $500 an hour in production losses.

In addition, to deliver an equal amount of liquid across the whole machine, all stream-carrying interiors had to be perfectly smooth; so the more than 1,000 feet of welding had to be performed without deformation, icicles, crevices or undercuts.

AISI Type 304 Nickel stainless steel was chosen by engineers because it combined high strength and hardness with good welding and forming characteristics. Its bright, smooth 2B finish came straight from the mill—simplifying fabrication, and cutting the customer's costs.

The corrosion resistance of this Nickel stainless steel minimizes iron contamination and subsequent discoloration of bright paper stock. Nickel stainless steel simplifies slime control and cleaning, and its exceptional properties give it resistance to abrasion as well as to corrosion.

A Fourdrinier flow distributor is only one example of how Nickel stainless steels help to turn out pure and uniform paper products with minimum production losses. They are also serving well in such forms as piping, pumps, valves, and other equipment required in pulp and paper processing.

A Nickel stainless steel can well answer your metals problems in these applications. A letter to Inco's Technical Service Department will give you all the facts on the Nickel stainless steels that take care of the hardest pulp and paper problems.

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street INCO New York 5, N. Y.

INCO NICKEL

NICKEL MAKES STAINLESS STEEL PERFORM BETTER LONGER

FOR IMMEDIATE DELIVERY

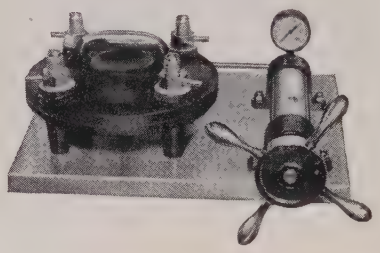
Tappi Standard

Pulp Testing and Sheet Making Apparatus

TAPPI SHEET MAKING MACHINE

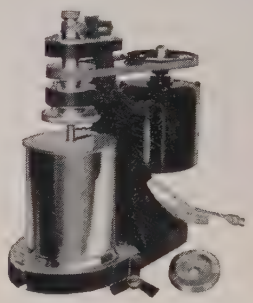
Bronze, brass and stainless construction throughout except couch roll which is heavily chrome plated. Drying Rings with gaskets and Drying Discs available but not illustrated. (T-205 m)

TAPPI PUMP & PRESS



Mounted on 18-8 Stainless steel base. Press on base, or pump only may be purchased separately. (T-205 m)

TAPPI DISINTEGRATOR



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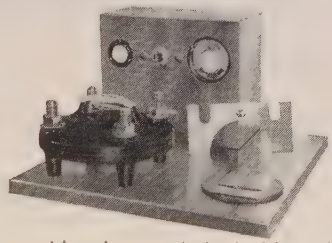

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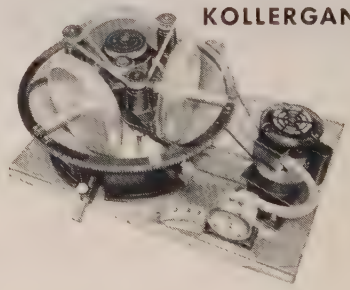

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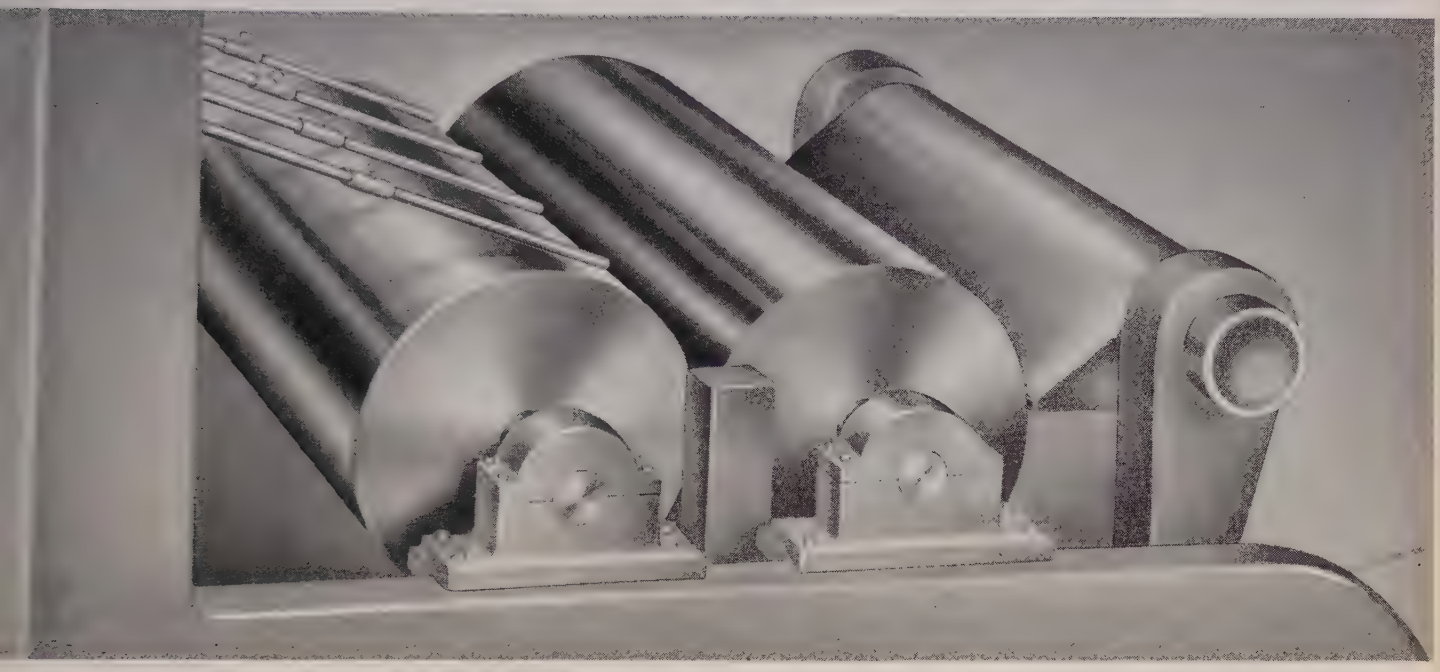

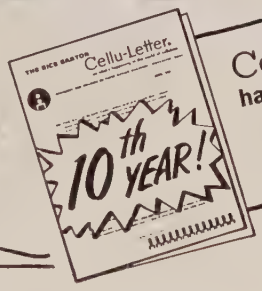

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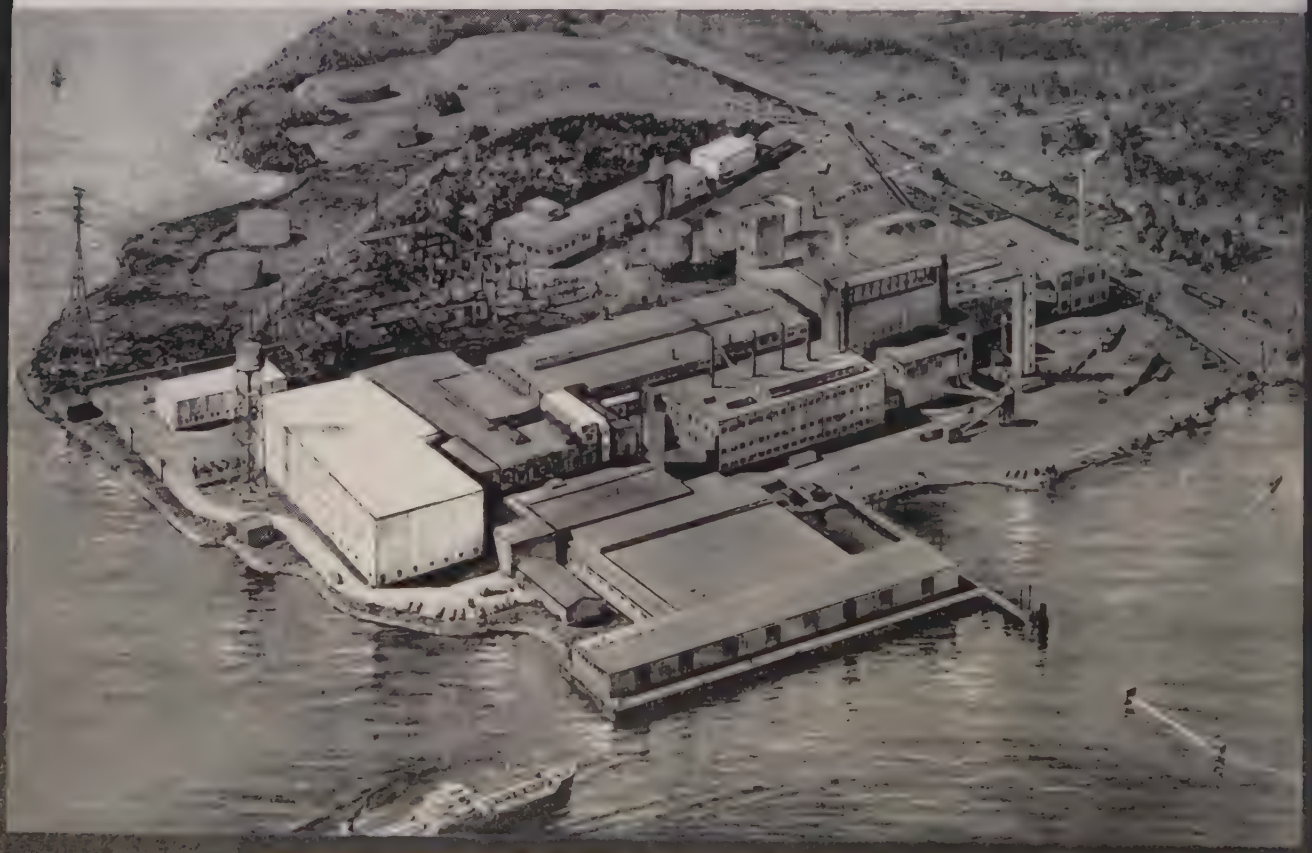

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Fundamentals of Drying Porous Materials

A. H. NISSAN and D. HANSEN

The paper is in two parts. The first discusses the application of the well-known laws of heat and mass transfer to drying, the influence of the nature of the solid on the falling-rate period, and the significance of two characteristic temperatures: the wet-bulb and the pseudo-wet-bulb temperatures. Methods for calculating temperature and moisture distributions in the falling-rate period are discussed. The second part considers the particular problem of drying sheet materials on heated cylinders. Relationships derived from the basic equations of heat transfer have been used to describe the temperatures and drying rates observed on a multicylinder machine. The use of these relationships for a detailed analysis of water removal and temperature distribution has been demonstrated by comparison of some calculations with data obtained on an experimental drying cylinder.

THE FUNDAMENTALS of drying present two types of problems: 1. A general problem: the mechanisms of heat and mass transfer by which wet solids dry. These mechanisms determine the partial differential equations to be set. 2. A special problem: the manner in which these general mechanisms operate on a particular machine where the geometrical and kinematic constraints set the boundary conditions for the partial differential equations to be solved.

NOMENCLATURE

C_p = heat capacity of water vapor, B.t.u./lb.
D_L = volumetric diffusivity, sq. ft./hr.
h = heat transfer coefficient between evaporation surface and air, B.t.u./(sq. ft.)(hr.)(°F.)
H = heat transfer coefficient, B.t.u./(sq. ft.)(hr.)(°F.)
k = thermal conductivity, B.t.u./(ft.)(hr.)(°F.)
k_g = mass transfer coefficient, sq. in./sq. ft. hr.
M_L = molecular weight of water, lb./lb. mole
p_a = partial pressure of water vapor in the air stream, p.s.i.
p_s = vapor pressure of water at temperature of wet solid, p.s.i.
p_{wb} = vapor pressure of water at the wet-bulb temperature, p.s.i.
P_a = partial pressure of water vapor in the air stream, lb./sq. ft.
P_{wb} = vapor pressure of water at the wet-bulb temperature, lb./sq. ft.
q = heat transferred, B.t.u./sq. ft./hr.
r = dimensionless distance, x/X
R = gas constant, B.t.u./(lb. mole)(°F.)
R_1 = dimensionless heat transfer coefficient at sheet-cylinder interface = H_1X/k
t_a = air temperature, °F.
t_c = temperature of cylinder surface, °F.
t_0 = initial temperature, °F.
t_s = temperature of wet solid, °F.
T = absolute temperature, °R.
w = quantity of water evaporated, lb/sq. ft.
W = dimensionless quantity of water removed = $\alpha\lambda w/Xkt_0$
x = distance through thickness of sheet, ft.
X = total thickness of sheet, ft.
y = mole fraction
α = thermal diffusivity, $k/\rho C_p$, sq. ft./hr.
ϵ = void fraction in solid
θ = time, hr.
λ = latent heat of vaporization, B.t.u./lb.
τ = dimensionless time parameter, $\alpha\theta/X^2$ (Figs. 5 and 6)
τ = characteristic time constant, hr. [eqns. (8) and (9)]
ρ = density, lb./cu. ft.

Subscripts

a = air
b = boiling point
c = cylinder surface
f = felt
s = solid
wb = wet bulb
pwb = pseudo-wet-bulb
1 = cylinder-sheet interface
2 = exposed sheet surface or sheet-felt interface

A. H. NISSAN and D. HANSEN, Interdisciplinary Materials Research Center Rensselaer Polytechnic Institute, Troy, N. Y.

I. THE DRYING PROCESS IN GENERAL

The Mechanisms of Drying

To make our studies as general as possible, we will consider simply a porous wet solid with one surface exposed to a stream of unsaturated air. Water will evaporate from the wet surface into the air. In doing so, a quantity of heat, equal to the latent heat of evaporation plus the sensible heat necessary to bring the water to the temperature of the air will be abstracted from the surroundings. This heat will come from the water itself—by depressing the average temperature—from the air, from an outside source of heat, or from a combination of these sources. Thus two transport phenomena are involved: one of heat flow into the water surface, and a second of mass flow from this water surface into the air. A steady state will obtain when these transports are in balance.

Further, to simplify the problem, we will consider the system where the only source of heat is the air stream. Hot, unsaturated air at a constant temperature flows over a somewhat colder, but very wet porous solid. Studies of a great number of such systems by many scientists have revealed certain generalizations. These may be summarized as follows:

1. At first there is a period during which the rate of drying is constant. This constant rate obtains while the water content of the solid is decreasing from an initially "saturated" condition.

2. At a particular critical moisture content, dependent on the specific system, the rate of drying begins to decrease.

3. From the moment the critical moisture content is reached until the solid is finally "dry" there is the "falling-rate period," during which the rate of drying is continuously decreasing. The rate ultimately becomes zero.

The moisture content at which drying ceases—the rate becomes zero—is itself not necessarily zero. It is an equilibrium moisture content at which the vapor pressure of water associated with the solid is equal to the partial pressure of water in the air stream. This moisture remaining after the drying has ceased is designated as the "bound" or "equilibrium" water content.

The total water content is thus made up of two portions: the bound water and the free water. The free water content is that water free to evaporate and equals, at any instant, the excess of the total moisture content over the equilibrium moisture content.

The free water is equal to the total moisture content only when the air is absolutely dry. Conversely, the free water content is zero, even for a saturated wet solid, when the air is itself saturated.*

Thus a study of drying resolves itself into a study of: (1) the constant-rate period of drying, and (2) the falling-rate period of drying.

The "free water content," "critical water content," and "equilibrium water content" are controlling parameters which determine the beginning and end of each of the two periods. Although these parameters are subjects for interesting study in themselves, they will be considered as "independent variables"; i.e., known and independently determined properties of the system.

The generalizations listed above are for the case of drying into an air stream where the air is the only source of heat for the material being dried. They do not apply rigorously to drying where heat is supplied directly from an external source, or by conduction through the drying bed at a rate which may be influenced by the varying conductivity of the bed as moisture is removed. However, the general idea of two regimes in which drying rate is controlled by different phenomena is still applicable and useful.

The Constant-Rate Period

This period ensues immediately upon establishment of steady state conditions in the drying apparatus. It is unique because the drying rate during this period is generally independent of the material being dried (unless the material is water soluble and so affects the vapor pressure).

At steady state the heat flowing into the wet solid (from the air, by conduction through the bed of wet solids, or from other external sources such as radiation) must be equal to that removed by the evaporated water. Again, considering the simplified case where the air stream is the only heat source, the balance may be derived as follows:

The rate of heat absorption per unit area is:

$$\frac{dq}{d\theta} = h(t_a - t_s) \qquad (1)$$

Simultaneously evaporation occurs at the exposed surface at a rate given by:

$$\frac{dw}{d\theta} = k_g(p_s - p_a) \qquad (2)$$

For the evaporation of a given quantity of water, w, from the material, the heat removed thereby is:

$$q = w[\lambda + C_p(t_a - t_s)]$$

differentiating:

$$\frac{dq}{d\theta} = [\lambda + C_p(t_a - t_s)]\frac{dw}{d\theta} \qquad (3)$$

Then substituting from equation (2) in equation (3):

$$\frac{dq}{d\theta} = [\lambda + C_p(t_a - t_s)]k_g(p_s - p_a) \qquad (4)$$

Since we are considering the steady state, equation (1) must equal equation (4) or:

$$h(t_a - t_s) = [\lambda + C_p(t_a - t_s)]k_g(p_s - p_a) \qquad (5)$$

As has been verified by many workers, the ratio of the heat transfer coefficient and mass transfer coefficient, h/k_g, can be related directly to intrinsic properties of the air stream (heat capacity, viscosity, conductivity, etc.). The Chilton-Colburn "j factor" analogy (*1*) is a well-known method of relating these coefficients. Since p_s is directly a function of t_s, then equation (5) directly relates t_s to the temperature, humidity (p_a) and other intrinsic properties of the air. The term t_s is thus uniquely determined by the conditions of the air stream (note that properties of the solid, velocity of the air stream, or geometry of the drier do affect this) and is indeed the well-known "wet bulb temperature." Hence equation (2) may be re-written:

$$\frac{dw}{d\theta} = k_g(p_{wb} - p_a) \qquad (6)$$

Equation (6) describes the constant-rate period drying rate in terms of a pressure difference defined by the conditions of the air stream, and a mass transfer coefficient dependent on the air velocity and geometry of the drier.

If a similar balance is made for the situation where additional heat is supplied, at a constant rate, by conduction or radiation a similar result is obtained.

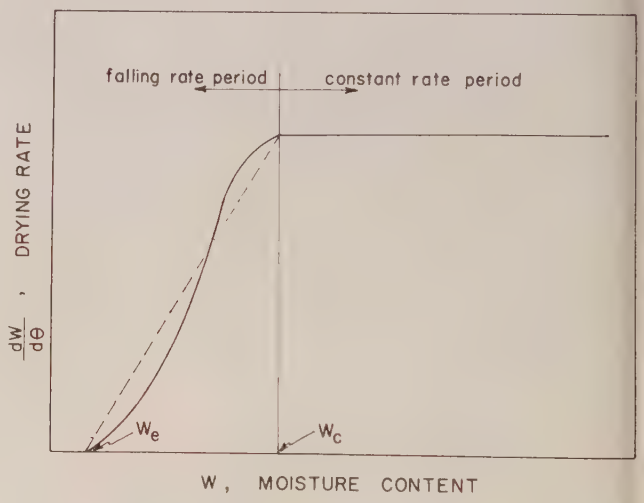

Fig. 1. General drying-rate curve

However, the temperature attained by the wet solid is not t_{wb}, but some greater value.

The Falling-Rate Period

Physically, the differentiation between the constant and falling-rate periods is due to the influence of the solid on the drying rate during the falling-rate period. During the constant-rate period the problem is essentially that of evaporation from a water surface. However, after the critical moisture content is reached

* Evaporation of water from a wet body into a saturated air stream can take place when the water surface temperature is higher than the air temperature. This is because the boundary layer is heated and becomes unsaturated. However, as soon as the boundary layer mixes with the bulk of the air a mist ensues, which will deposit on ducts and other surfaces—generally an undesirable condition.

the surface is no longer completely wetted, and drying rate becomes dependent on the forces supplying water to the surface as well as the driving forces for evaporation.

Figure 1 is a generalized graph of drying rate during the constant and falling-rate periods. The exact shape of the curve in the falling-rate period depends on the controlling material transport forces in the solid. Several are involved; including gravitational, capillary, friction, and diffusion. Which of these is the controlling force depends on the nature of the solid. Particularly it depends on the sizes and distribution of pores. Since the relative influence of the different forces will vary with the quantity of water in the pores, one may control for part of the falling-rate period and others, for another part.

For these reasons the exact analytical determination of drying rates during the falling-rate period is exceedingly complex. Arbitrary simplifications are generally employed in drier design calculations. One such approximation technique is indicated in Fig. 1 by the dashed straight line drawn from the point of intersection of the critical-moisture content with the constant-rate-period line, to the equilibrium moisture content at zero rate. This technique takes the drying rate as proportional to the free moisture content.

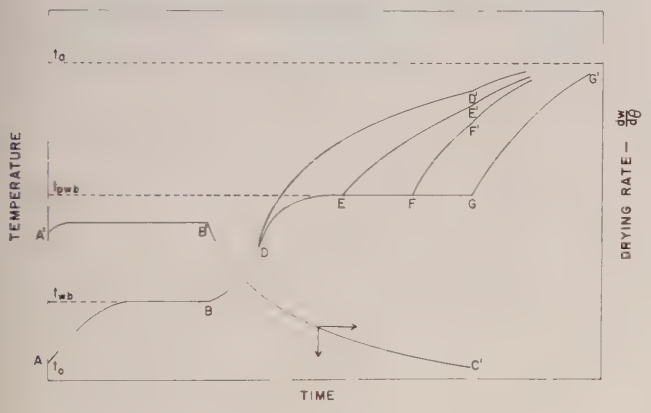

Fig. 2. Generalized time-temperature record

Another often used approximation applies diffusion equations to all, or part, of the falling-rate period. The accuracy obtained with these approximations will depend, naturally, on how much difference there is between them and the true falling-rate curve. Their usefulness will depend on this and the precision required in the particular calculation.

The complete analysis of a drying problem requires, in addition to the rate-of-drying relationships, a description of the temperature history during drying. That is, we require knowledge of the temperature of the material as a function of time and position.

For a porous wet solid being dried in an air stream it is well established that during the constant-rate period the material temperature tends to the wet bulb temperature of the air stream. When the drying is complete, the material will tend to the air temperature. There remains the description of temperature during the falling-rate period.

Nissan and co-workers (*2, 3, 4*), in a series of experiments on the drying of Terylene (British polyester fiber corresponding to Dacron), wool, sand beds, and in unpublished work on thick beds of cellulose fibers, established the existence of a unique temperature obtained during the falling-rate period—the "pseudo-wet-bulb temperature." They also determined a method for calculating the pseudo-wet-bulb temperature and the manner in which the bed rises to this temperature. Work is proceeding on further studies of this phenomenon in different systems.

Figure 2 presents a generalized temperature–time diagram for a porous solid drying in an air stream. Starting from point A (t_0) at time zero, the temperature rises to the wet bulb temperature t_{wb}. After the critical moisture content is reached, B, the material rises to the pseudo-wet-bulb temperature, t_{pwb}, along curve BDE. As portions of the bed, starting at the exposed surface, become dry their temperatures rise toward the air temperature—curves E–E', F–F', and G–G'. The exposed surface becomes dry before the pseudo-wet-bulb temperature is attained and follows the curve D–D'. The rate-of-drying curve corresponding to this temperature history is included in the figure—curve $A'B'C'$.

To calculate the pseudo-wet-bulb temperature, Nissan, Kaye, and Bell (*1*) derived a relationship based

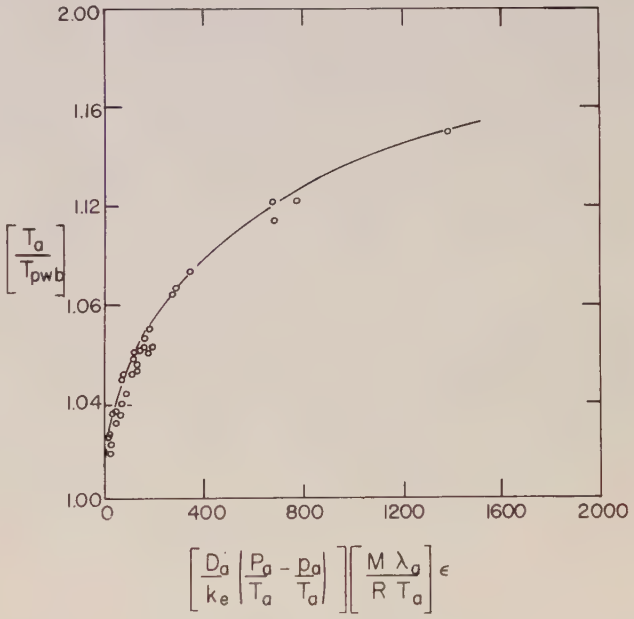

Fig. 3. Pseudo-wet-bulb temperature as function of air temperature

on the heat balance and vapor transport in the material during the falling-rate period. The resulting equation is:

$$\frac{T_a}{T_{pwb}} = 1 + 1.285\left[\frac{D_{pwb}}{k}\left\{\frac{P_{pwb}}{T_{pwb}} - \frac{P_a}{T_a}\right\}\right] \times \left[\frac{M_L \lambda_{pwb}}{RT_{pwb}}\right] \epsilon \times 10^{-3} \quad (7)$$

Experimental results were correlated with this equation and fairly good agreement was obtained. The usefulness of this equation in predicting T_{pwb} is severely hampered by the fact that it includes several air and water properties to be evaluated at the unknown T_{pwb}. Hence a graphical correlation was prepared, retaining the form of the dimensionless parameters

appearing in equation (7), but evaluating the different properties at T_a rather than T_{pwb} (4). On the basis of data from four different systems a good general correlation is obtained (Fig. 3). This figure represents a method of predicting pseudo-wet-bulb temperature directly from properties of the air stream.

To complete the quantitative description of temperature history during drying it is necessary to predict the curves for describing the attaining of T_{wb}

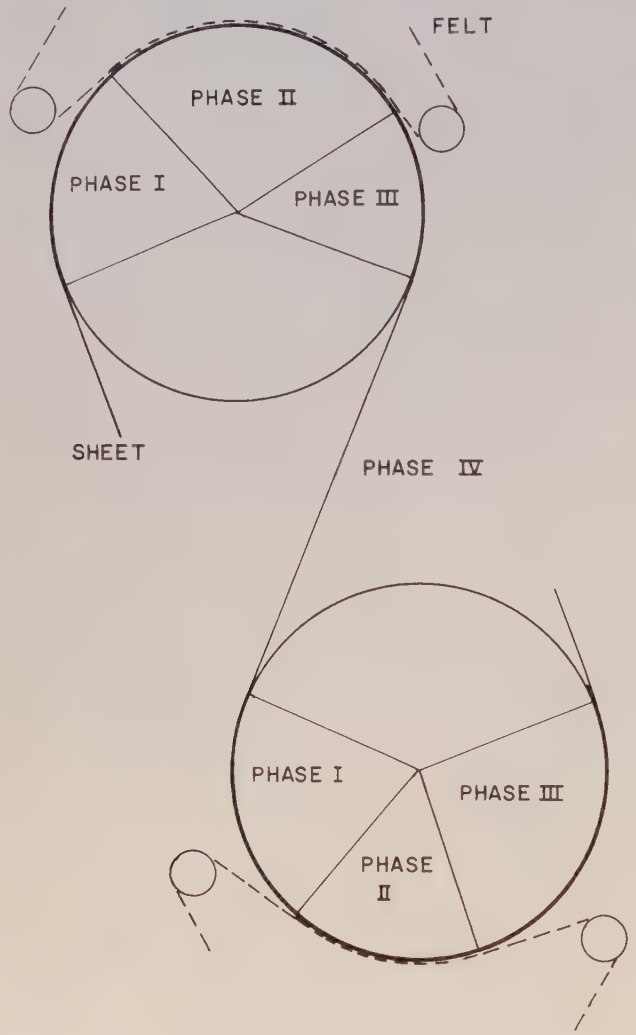

Fig. 4. Phases on drying cylinder

during the establishment of the constant rate period; and likewise for the approach to T_{pwb} during the transition from the constant to falling-rate period. In a previous paper (4) similar equations for these predictions were derived and checked with experimental results. The equation is, where temperatures are tending to the wet-bulb value:

$$t = t_0 + (t_{wb} - t_0)(1 - e^{-\theta/\tau}) \qquad (8)$$

Where temperatures are tending to the pseudo-wet-bulb value (the term τ is a time constant for the system and has the same value in both equations) the equation is:

$$t = t_{wb} + (t_{pwb} - t_{wb})(1 - e^{-\theta/\tau}) \qquad (9)$$

Following the same line of reasoning used to arrive at the temperature relationships, it was attempted to derive quantitative relationships describing liquid distribution and drying rates during the falling-rate period. A satisfactory relationship was developed for the case of flat beds. This analysis was considerably more complex than that for temperatures. It was necessary to employ one arbitrary function in obtaining a solution (the alternative was formulation of the fluid dynamics of nonisothermal flow in porous media) and as this solution applied only to flat beds it was less general than those for temperature. However, a method of analysis was demonstrated which could be extended to systems other than flat beds.

Thus, an approximate, though not a final, method exists for elucidation of the internal processes which obtain when porous solids are dried in a stream of air.

II. DRYING ON CYLINDER MACHINES

Mechanisms of Cylinder Drying

Cylinder drying differs fundamentally in several aspects from the type of process considered in Part I. Most important of these are the facts that: (1) the primary source of heat is by conduction through the cylinder shell; (2) the total drying time is generally of such small magnitude that a steady state is not established and the drying operation is a transient phenomenon. That is, while the entire process may be at a steady state with regard to the machine, if we consider a specific portion of paper or board, it is not at steady state but is subject to constantly varying conditions as it passes through the machine.

Hence, the characteristics and generalizations pertinent to the usual constant-rate period and falling-rate period do not apply directly to cylinder drying. However, the general concepts are pertinent if we consider the constant-rate period as that portion of the drying operation governed by the laws pertaining to evaporation from a water surface, and consider the falling-rate period as the portion of the drying operation where the laws of fluid dynamics and evaporation within the pores of the material must also be considered.

Theory of Cylinder Drying

If we consider a diagram of a cylinder drier, such as Fig. 4., we can break the operation into a series of four phases for each of which we can formulate the equations describing the temperature variations and drying rate. The four phases are: (I) where the sheet first contacts the cylinder, (II) where the sheet is covered by a felt, (III) where the sheet is again exposed, and (IV) the space between cylinders, or the draws. On an unfelted cylinder there is no phase II, and actually only phases I and IV. In this way a machine of any number of felted and/or unfelted cylinders may be described, in a general way, as a series of phases.

One general partial differential equation can be written to describe the cylinder drying process:

$$\frac{\partial^2 t}{\partial x^2} = \frac{1}{\alpha}\frac{\partial t}{\partial \theta} \qquad (10)$$

To complete the description it is necessary to specify the boundary conditions applying in each separate phase. The solution of the above equation with its boundary conditions translates that description into

specifications of sheet temperatures and drying rates at specific machine positions.

The derivation of the above equation has been presented in earlier publications (*5*, *6*). In the first of these papers an approximate solution was obtained and applied to some calculations on an industrial machine. In the second, more exact solutions were obtained for the specific case of drying on an unfelted cylinder. These solutions were compared with data obtained on an experimental machine.

If we consider the constant-rate period, the necessary boundary conditions for solving equation (10) pertain to: (1) the initial temperature distribution, (2) the heat transfer conditions at the exposed (or felt covered in phase II) surface. A solution for the falling-rate period would also involve the internal mass transport phenomena controlling flow of water to the

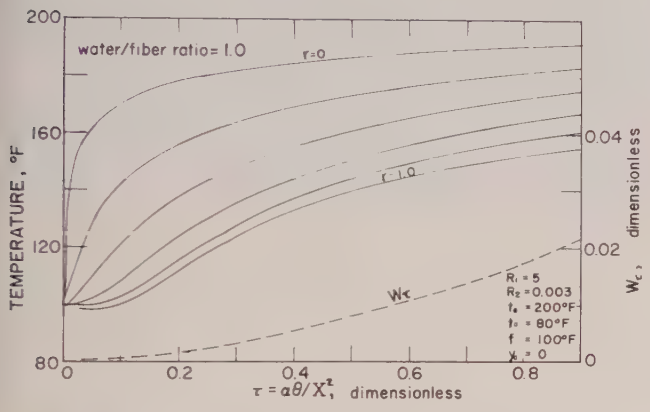

Fig. 5. Calculated temperature distribution

evaporation surface. Taking the simpler case, the constant-rate period, the complete formulation, with boundary conditions is as given in Table I.

An exact analytical solution to the problem formulated in Table I is not available. Several approximate solutions have been derived, and in one case applied to the calculation of water removal on a specific industrial machine (*5*). In that case the calculations and measured values on the machine agreed quite well. These approximate solutions, are, even so, fairly complex and yield numerical results only as a product of tedious calculations. Also, by the nature of their derivation, these solutions will yield only a mean sheet temperature.

Hence, in order to obtain the exact solutions necessary for a description of temperature variations with time and position, the equations in Table I were translated into finite difference forms and exact numerical solutions obtained using a digital computer (IBM-650). The details of obtaining these solutions have been presented in (*6*). An example of the type of solution obtained is given in Fig. 5 for phase I. The curves in Fig. 5 represent the change of temperature with time at different positions through the thickness of the sheet ($r = 0$ represents the surface adjacent to the cylinder; $r = 1$ the outer surface; and the others intermediate planes). The time scale is in terms of a dimensionless group, $\alpha\theta/X^2$, where α is thermal diffusivity, θ is time, and X is sheet thickness. The dashed line in Fig. 5 gives the total water removed in phase I as a function of time. Again this variable is given as a dimensionless group, W_τ. The parameters listed on the figure pertain to the values of heat transfer coefficients, initial temperature, and cylinder temperature for which this particular set of curves apply.

Applications of the Theory

To verify the theory and test the solutions, and also to demonstrate their applications, several experiments

Table I. Formulation of the Cylinder Drying Problem

Differential equation:

$$\frac{\partial^2 t}{\partial x^2} = \frac{1}{\alpha}\frac{\partial t}{\partial \theta}$$

Initial condition:

$$t = f(x) \text{ for } \theta = 0$$

Boundary conditions:

Phase I and III

$$\left(\frac{\partial t}{\partial x}\right)_{x=0} = -\frac{H_1 X}{k}(t_c - t_{x=0})$$

$$\left(\frac{\partial t}{\partial x}\right)_{x=X} = -\frac{H_2 X}{k}(t_{x=1} - t_a) - (4.65H_2X/k)(y_1 - y_a)t_b$$

Phase II

$$\left(\frac{\partial t}{\partial x}\right)_{x=0} = -\frac{H_1 X}{k}(t_c - t_{x=0})$$

$$\left(\frac{\partial x}{\partial t}\right)_{x=X} = -\frac{H_2 X}{k}(t_{x=1} - t_f) - (4.65H_2X/k)(y_1 - y_f)t_b$$

Phase IV

$$\left(\frac{\partial t}{\partial x}\right)_{x=0} = -\frac{H_1 X}{k}(t_a - t_{x=0}) + (4.65H_1X/k)(y_0 - y_a)t_b$$

$$\left(\frac{\partial x}{\partial t}\right)_{x=X} = -\frac{H_2 X}{k}(t_{a=1} - t_a) - (4.65H_2X/k)(y_1 - y_a)t_b$$

were conducted on a cylinder drying apparatus specifically constructed for this purpose. Composite muslin sheets were used for the drying material, and temperatures were recorded at internal points using extremely fine thermocouples. An example of the agreement of

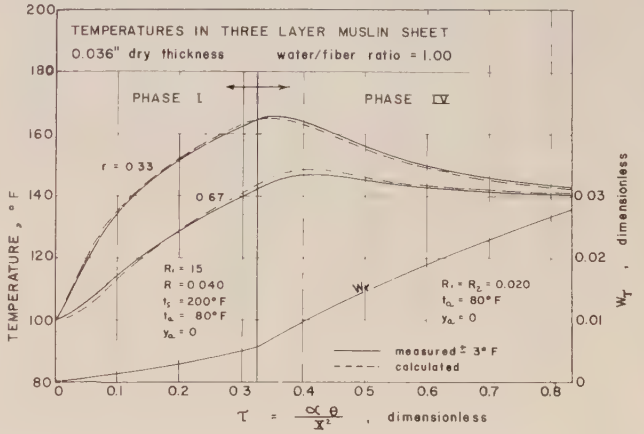

Fig. 6. Comparison of measured and calculated temperatures

measured and calculated temperature values are given in Fig. 6. Since this was an unfelted cylinder only phases I and IV were present. The data from these experiments also permitted the comparison in Fig. 7. On the experimental machine water was removed from

the sheet in three places: (1) evaporation from the exposed surface in phase I, (2) evaporation from both faces in phase IV, and (3) by partition between sheet and cylinder as the sheet leaves the cylinder.

The values for evaporation in phases I and IV were obtained (calculated) from the numerical solutions. The quantity removed by partition was measured in separate experiments on a cold cylinder. It is seen from Fig. 7 that the sum of these three add up to about 90% of the total water removed (also experimentally measured). The difference is attributed to two sources: (1) errors in experimental measurements, (2) differences between partition on a hot cylinder compared to a cold one. The measurement of water removed by partition was made on a cold cylinder (to avoid evaporation), whereas the rest of the analysis applies to a heated cylinder (200°F.).

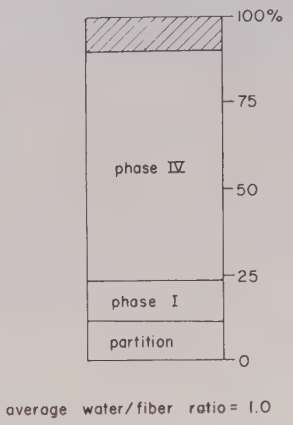

Fig. 7 Analysis of water removal

In comparing the relative amounts of water evaporated in phase I compared to phase IV it is noted that under the conditions of the experiment the sheet came onto the cylinder relatively cold (100°F.) and also that the length of phase I was 1.7 sec. compared to 2.5 sec. for phase IV.

Heat transfer coefficients between the sheet and cylinder surface were also determined in this analysis. Values ranged from 290 B.t.u./(sq. ft.)(hr.)(°F.) to essentially infinity, depending on the moisture content of the sheet.

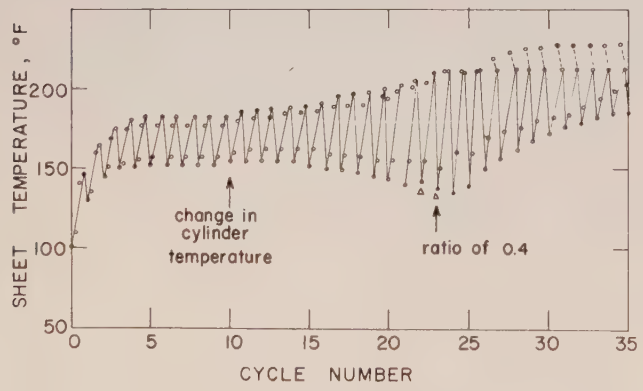

Fig. 8. Drier temperatures

As mentioned above, comparisons were also made of data from an industrial machine against values calculated from approximate solutions to the theory. The comparison of calculated and measured drying data are given in Table II. Another of the applications of the approximate solutions to a multicylinder machine is demonstrated by Fig. 8. The cyclic high and low points represent the mean sheet temperature attained in each phase on each cylinder and in the draws, respectively. (One cycle corresponds to a cylinder and the draws following it.) Direct calculation for the cylinders at the far end of the machine indicate temperatures in excess of 212°F. This may be possible if the felt provides sufficient pressure. The drying figures in Table II, however, were based on a maximum attainable temperature of 212°F.

Table II. Drying Data

	lb. Water per lb. solid	
	Av. measured	*Calculated*
After cylinder no.		
6	1.94	1.7
12	1.56	1.3
18	0.80	0.8
24	0.18	0.3
30	0.07	0.05
36	0.056	0.01

SUMMARY

In describing a drying operation we are interested first in the drying rate and also in the temperatures and moisture distribution obtaining within the wet solid. During the constant-rate period these items are determined by the interaction of the mechanisms for heat and mass transfer at the surfaces of the drying material. For a porous solid drying in a heated air stream this interaction results in the wet-bulb temperature in the solid.

The falling-rate period is more complex, for here the internal mechanisms governing heat and moisture transport within the solid must be considered as well as the surface conditions. For a porous solid drying in a heated air stream, however, the solid tends to a characteristic temperature intermediate between the wet-bulb value and the temperature of the air stream. This characteristic temperature has been designated the pseudo-wet-bulb value.

The differential equations derived from the basic laws of heat and mass transfer can be used to describe the cylinder drying process. However, the conditions and geometry of a cylinder drier define boundary conditions to be used with these equations which together define a complex mathematical problem not amenable to an analytical solution. The examples discussed in this paper demonstrate how the theoretical equations may be applied to do two things:

1. Through approximate solutions to describe the operation of a multicylinder machine, and to compare separate cylinders and phases.
2. Through "exact" numerical solutions to describe in detail the temperatures obtaining in the web on a specific cylinder, and to analyze in detail the drying accomplished on that cylinder.

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A Study of the Resistance of Woven Wool Felts to Liquid Flow

JAMES E. MACKLEM

The contributions of different structural variables of a woven wool felt to its resistance to the flow of water in a direction normal to the felt (transverse direction) and in a direction along the felt (lateral direction) has been considered. Lateral and transverse permeability data for the viscous flow of water through several specially constructed woven felts were correlated over a wide porosity range by the Kozeny-Carman equation. Although the hydraulic radius concept upon which this theory is based as designed primarily for unconsolidated, randomly oriented porous media, a reasonably good correlation was obtained for these woven structures. The transverse permeability of all samples was not affected too greatly by the structure, being characterized by a fiber orientation predominantly normal to flow. A decrease in the effective specific volume of the swollen fiber was observed for all samples under high compression. The lateral permeability was particularly dependent upon the availability of the pore space in the warp yarns which were always oriented parallel to flow. Any disturbances in the parallel orientation of the fibers in these yarns whether caused by variations in the number of fill yarns per inch, the weave pattern, or the applied load significantly affected the permeability. Yarn size and napping had little effect on the permeability.

NOMENCLATURE

A	=	cross-sectional area of a porous bed normal to flow, sq. cm. (area of the test zone in this study)
c	=	mass of fibers per unit volume of bed, g. per cc.
d	=	fiber diameter, cm.
g	=	acceleration due to gravity, 980 cm. per sec.^{2}
K	=	transverse permeability coefficient defined by Darcy's law, sq. cm.
K_2	=	lateral permeability coefficient, sq. cm.
k	=	Kozeny constant, $k = k_0(L_e/L)^2$, dimensionless
L	=	depth of a porous bed in the flow direction, cm.
L_2	=	width of felt sample in lateral permeability determination, cm.
L_e	=	length of equivalent channels in a porous bed, cm.
L_0	=	depth of bed at zero porosity, cm.
M, N	=	empirical constants in compressibility equation, $c = MP^N$
m	=	mean hydraulic radius, cm.
ΔP	=	frictional pressure drop across a porous bed, dynes per sq. cm.
P	=	compacting load on the pad, kg. per sq. cm.
q	=	volumetric rate of flow, cc. per sec.
S_v	=	specific surface of fibers, surface area per unit volume of fibers, sq. cm. per cc.
S_w	=	specific surface of fibers, surface area per unit mass of fibers, sq. cm. per g.
v	=	effective specific volume of the fibers, cc. per g.
W	=	total mass of fibers in the bed, g.
ϵ	=	fractional void volume of the porous bed, dimensionless
μ	=	viscosity of the fluid, poises

A KNOWLEDGE of the nature of the resistance of woven wool felts to the flow of water is desirable for the improvement of our understanding of the mechanism of water removal in the press section of the paper machine. The complex yarn and fiber orientation of the woven felt exclude it from the types of porous media for which flow relationships have been established, and the contribution of such structural factors as weave pattern, napped surfaces, yarn size, and the number of yarns per inch to the flow resistance is not well understood. The influence of the yarn and fiber orientation upon the flow resistance is of a different nature for flow along the felt in the machine direction than for flow normal to the felt, making a knowledge of both desirable. The present investigation was limited to a study of viscous single-phase flow, because it is better understood than other types of flow through fibrous beds and permits a better characterization of the flow in relation to the physical properties of the medium.

Previous investigations of flow through ordinary open weave textiles are not applicable to the close weave and less highly twisted yarns of woven press felts. Of interest to this investigation is the considerable amount of work concerned with the flow resistance of fibrous beds having a random or a known fiber orientation.

The resistance of a porous material to viscous fluid flow, obtained from rate and driving-force relationships, has been related to the shape, size, and orientation of the particles comprising the bed. Particularly useful in this connection is the Kozeny-Carman equation which expresses the viscous flow resistance of an unconsolidated porous bed in terms of certain physical properties of the material composing the bed. In the derivation of this equation the assumptions are made that (1) the pore space may be regarded as a bundle of parallel capillaries with a common hydraulic radius and a cross-sectional shape representative of the average shape of a pore cross section; (2) the path of a streamline through the bed is tortuous, the average length being greater than the bed length; (3) the basic mechanism is capillary flow; (4) no pores are sealed off; (5) the pore size is uniform; (6) the pores are randomly oriented; (7) diffusion and surface effects are absent. This equation, originally derived by Kozeny (*1*), modified by Carman (*2*) and discussed by others (*3*, *4*, *5*) relates the permeability coefficient, K, defined by Darcy's law:

$$K = \frac{q\mu L}{A\Delta P} \qquad (1)$$

to the bed properties in the following manner:

$$K = \frac{\epsilon^3}{(1-\epsilon)^2 k S_v^2} \qquad (2)$$

where q is the volumetric flow rate of an indifferent fluid of viscosity mu through a porous bed of cross-sectional area, A, and depth, L; ΔP is the pressure drop across the bed. The external surface area per unit volume of the particles is designated as S_v, and the porosity, defined as the volume of voids per unit volume of bed, is designated as ϵ. The factor k,

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usually termed the "Kozeny Constant" may also be expressed as the product of a pore shape factor k_0, related to the pore cross section, and the tortuosity (L_e/L),[2] where L_e is the length of the tortuous path taken by the fluid through the bed.

The Kozeny-Carman equation has been verified experimentally for viscous flow through unconsolidated porous beds of many different shaped particles including spheres, sands, powders, glass fibers, and various textile fibers. Recent books by Scheidegger (*4*) and Carman (*6*) discuss some of the results of this previous work. The previous research of interest to this investigation will be briefly reviewed.

Robertson and Mason (*7*), investigating the water permeability of wood pulp, rayon, and cotton fibers pointed out that the void fraction, ϵ, represents the portion of the bed volume available to the flowing fluid and for fibers that swell in water should be expressed as

$$\epsilon = 1 - vc \qquad (3)$$

where c is the mass of fibers per unit volume of bed, and v is the effective specific volume of the swollen fiber. Substitution of the above value of ϵ in equation (2) and rearrangement of terms yielded the following rectified form of the Kozeny-Carman equation:

$$(Kc^2)^{1/3} = \left(\frac{1}{kS_w^2}\right)^{1/3}(1 - vc) \qquad (4)$$

where S_w is the surface area per unit mass and equals vS_v. A graphical treatment of permeability data taken at different bed densities in the form suggested by equation (4) was linear over the porosity range where the equation was valid, and the slope and intercept of the line yielded respectively values of kS_w^2 and v.

Carroll and Mason (*8*) observed good agreement between the specific volume of nylon, acetate, and viscose rayon fibers determined by a displacement technique and specific volume determined by permeability using a nonswelling liquid. Specific volumes determined on the same fibers using water as the permeating fluid showed fair agreement with values calculated from moisture regain and centrifuging measurements. Deviations of the water-permeability data from the predicted linear relationship of equation (4) were observed at porosities less than 0.5 for wood pulp fibers, and were attributed to a deformation of the fiber either by collapse of the lumen or deswelling of the wall by the applied compressive load.

Another useful rectified form of the Kozeny-Carman equation is given by Fowler and Hertel (*9*). If one considers a porous bed so highly compressed that the void volume is zero, the effective particle and bed density are the same and equal to W/AL_0, where L_0 is the bed thickness at zero porosity and W is the mass of particles in the bed. At any other thickness L the solid fraction of the bed is L_0/L and the porosity is $1 - L_0/L$. Substituting this quantity for ϵ in equation (2) yields

$$(KL)^{1/3} = \left(\frac{1}{kS_v^2L_0^2}\right)^{1/3}(L - L_0) \qquad (5)$$

where k, S_v and L_0 are constant, a plot of $(KL)^{1/3}$ versus L is linear.

A plot of Brown's (*10*) air-permeability data for pulp fibers in the above form was linear in the porosity range 0.56 to 0.88 but deviated from linearity at lower porosities. Extrapolation of the lower curved portion of the plot gave a fiber density closely the same as that obtained for cellulose by displacement methods. Brown believed that the Kozeny constant increased with decreasing porosity in the low-porosity range, but Mason (*11*) has pointed out that under the high compressive pressures used, the effective specific volume of the fibers may decrease and gradually approach the specific volume of cellulose determined by gas displacement.

Several investigations have demonstrated the dependence of the Kozeny constant upon the porosity and fiber orientation. Fowler and Hertel (*9*), studying the air permeability of randomly packed beds of textile fibers, observed excellent agreement between specific surface values calculated from the Kozeny-Carman equation using an average value of the Kozeny constant of 5.55 and values calculated from microscopic measurements.

Sullivan and Hertel (*12*), investigating the air permeability of carefully oriented beds of glass spheres and glass fibers for which specific surfaces had been determined microscopically, observed a Kozeny constant of 4.5 ($\epsilon = 0.39$) for randomly oriented surfaces, a k of 3.0 ($\epsilon = 0.87$) for fibers oriented parallel to flow, and a k of 6.0 ($\epsilon = 0.81$) for fibers oriented normal to flow.

From Emersleben's (*13*) mathematical analysis of flow parallel to uniform cylinders in square array, a decrease in the Kozeny constant with porosity may be predicted. Sullivan (*14*) in an investigation of flow through compact bundles of circular fibers oriented parallel to flow observed a decrease in the Kozeny constant with porosity from 3.0 at a porosity of 0.88 to 0.99 at a porosity of 0.35. Cotton fibers possessing an irregular cross section showed a smaller decline in the Kozeny constant with porosity, probably because of the incomplete parallel orientation of the irregular fiber surfaces.

Using wool fibers oriented parallel to flow, Anderson and Warburton (*15*) observed that the Kozeny constant was reasonably independent of porosity in the range 0.47 to 0.68 having an average value of 2.0. Using fibers of different diameters, values of the Kozeny constant ranging from 1.6 for coarse fibers to 2.5 for fine fibers were observed. Better parallelism probably was obtained with the more easily straightened coarse fibers. When the same fibers were cut into short lengths and packed randomly to a porosity of 0.7, a Kozeny constant of 6.1 was observed for all diameter fibers.

Other investigations (*16–19*) of the dependence of the Kozeny constant upon fiber orientation and bed porosity have been made for high-porosity beds ($\epsilon = 0.77$–0.99). In all cases the Kozeny constant increased with porosity but less rapidly in beds having a randomized or normal fiber orientation.

Happel (*20*) derived expressions for the dependence of the Kozeny constant upon porosity for viscous flow normal and for viscous flow parallel to a square array of circular cylinders. A decrease in k with ϵ was predicted in each case and at any porosity the value of k for a normal flow was approximately twice that for parallel flow. Happel pointed out that his analysis was probably not applicable for porosities lower than 0.4 to 0.5 but showed fair agreement with results of others at greater porosities.

Table I. Structure of Felt Samples
All felts have 48 warp ends per inch

Sample no.	*Basis weight, g./sq. cm.*	*Weave pattern*	*Picks per inch*	*Yarn size, American cut system*	*Finish*
1	0.0704	5 & 1 sateen	70	16	Natural
2	0.0702	3–3 plate	70	16	Natural
3	0.0552	3–3 plate	48	16	Natural
4	0.0512	5 & 1 sateen	48	16	Natural
5	0.0692	Duplex	70	16	Natural
6	0.0727	3–3 plate	48	11	Natural
7	0.0514	3–3 plate	70	20	Natural
8	0.0752	5 & 1 sateen	70	16	Nap
9	0.0752	3–3 plate	70	16	Nap
10	0.0545	Duplex	48	16	Natural
11	0.0595	3–3 plate	48	16	Nap

For flow parallel to fibers the decrease in the Kozeny factor with porosity can be attributed to a decreasing shape factor, because the tortuosity would be unity. Carman (*6*) points out that the small shape factors observed by Sullivan (*14*) for parallel flow at low porosities are reasonable, because the narrow triangular shaped channels, having a small value of k_0, extend the length of the bed. In randomly packed beds the flow channels continually break up, divide, and reconnect along the flow direction, and one may then speak of an average channel shape that varies little with porosity.

Application of the Kozeny-Carman equation to the permeability of woven textiles has been limited, because the relationship between the Kozeny factor and the complex fiber orientation of woven fabrics has not been studied. Grace (*21*), using the Kozeny-Carman equation with a Kozeny factor of 5, calculated an average pore size of a woven wool felt from permeability data (obtained with a nonswelling liquid) that was in good agreement with the modal pore size in the bulk of the felted structure obtained by a mercury intrusion technique. The data were obtained for one felt at one pad density only.

Very recently Ginn (*22*) measured the lateral and transverse air and water permeabilities for different commercial woven felts at various pad densities. A logarithmic plot of the calculated permeability constant against a calculated Kozeny-Carman porosity function, $\epsilon^3/(1-\epsilon)^2$, showed deviations from the predicted line of 45° slope which were of a different nature for the air and water permeabilities of the same felt. The deviations did not appear to be serious enough to completely invalidate the Kozeny-Carman theory for flow through woven felts, however.

In the present investigation it was desired to establish the validity of the Kozeny-Carman theory for viscous flow through woven wool felts. Having done so, the value of the Kozeny factor could be calculated from experimental data for the several felts at several pad densities. The research of others concerned with the dependence of the value of the Kozeny factor on the fiber orientation would then serve as an excellent basis for relating the effective fiber orientation to the felt structure.

EXPERIMENTAL SAMPLES

Several pairs of woven wool felt samples were carefully designed and constructed so that the members of each pair were identical in all structural properties but one.* Differences in the flow resistance between the felts of each pair could then be associated with the known structural difference. Eleven samples were so constructed to permit the investigation of three weave patterns, three yarn sizes, two pick counts (number of fill yarns per inch), and napped or natural finishes. All samples were fulled and the number of warp yarns per inch, the yarn twist, and grade of wool were the same for all felts. The structural properties of the samples are given in Table I. Yarn sizes are given in the American cut system, the cut being the number of 300-yd. hanks per pound. The weave patterns are shown diagrammatically in Fig. 1.

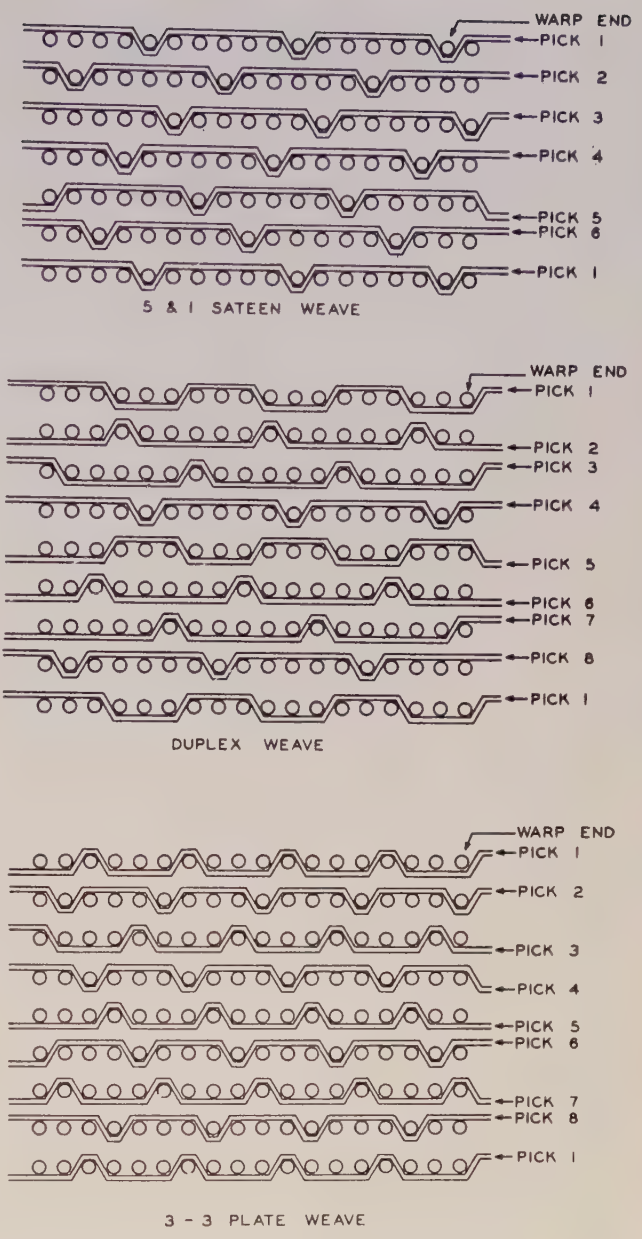

Fig. 1. Weave patterns

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Transverse Permeability Measurement

The transverse permeability cell shown in Fig. 2 was modeled after the filtration tube of Ingmanson (*3*) with some important modifications. A guarded zone, based on the annular guard ring principle of Carson (*23*),

* The Appleton Woolen Mills, Appleton, Wis., furnished the samples and assisted in their design.

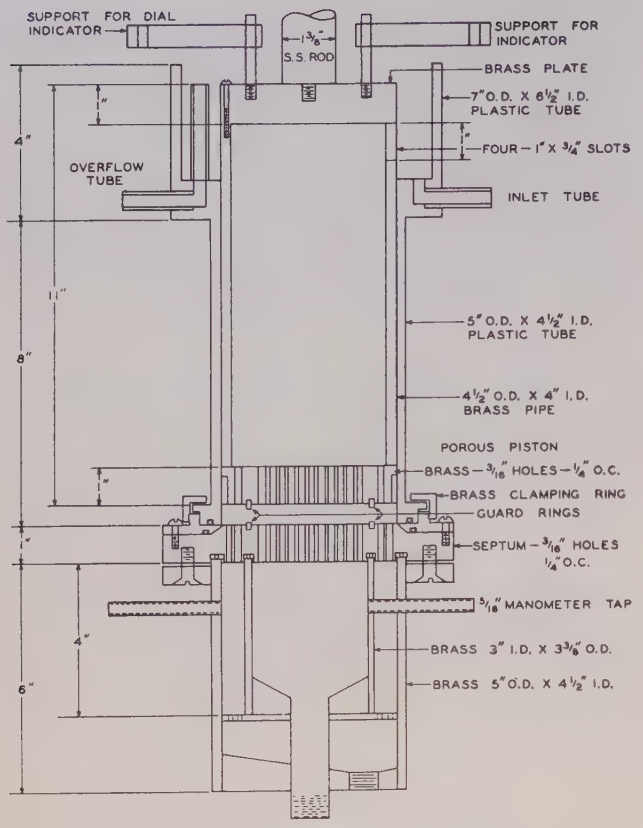
SUPPORT FOR DIAL INDICATOR
S.S. ROD
SUPPORT FOR INDICATOR
BRASS PLATE
7" O.D. X 6½" I.D. PLASTIC TUBE
FOUR – 1" X ¾" SLOTS
OVERFLOW TUBE
INLET TUBE
5" O.D. X 4½" I.D. PLASTIC TUBE
4½" O.D. X 4" I.D. BRASS PIPE
POROUS PISTON
BRASS – 3/16" HOLES – 1/4" O.C.
BRASS CLAMPING RING
GUARD RINGS
SEPTUM – 3/16" HOLES 1/4" O.C.
5/16" MANOMETER TAP
BRASS 3" I.D. X 3 3/16" O.D.
BRASS 5" O.D. X 4½" I.D.

Fig. 2. Transverse permeability cell

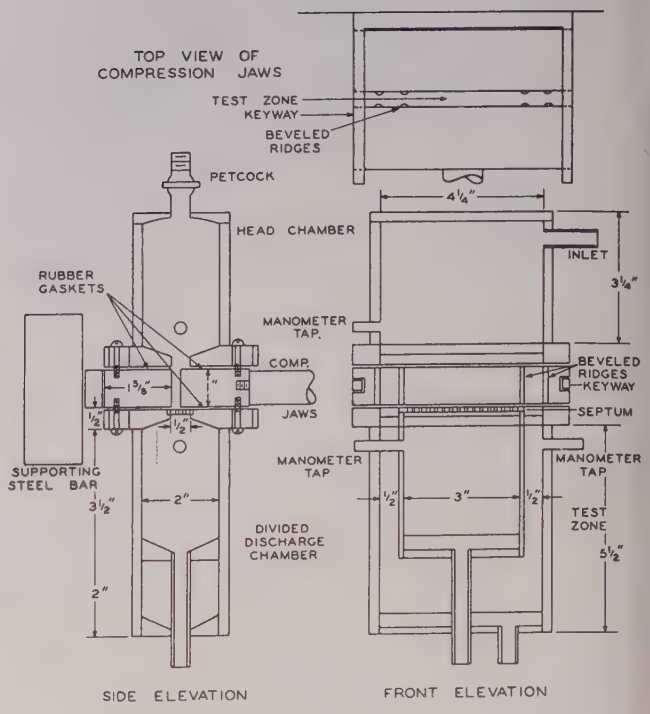

Fig. 3. Lateral permeability cell

was incorporated into the apparatus to eliminate flow along the felt toward the edges of the precut pad. Flow from the inner guard zone was separated from flow through the outer annulus of the pad with a divided discharge chamber below the septum. Separate turbine-type, centrifugal pumps and separate piping systems permitted separate adjustment of the flow rate in each zone allowing equalization of the pressure in the two compartments. Thus, there would be no flow laterally from the test zone to the guard zone. The constant head of water above the sample and the suction developed by the pumps below the sample provided the fluid pressure drop across the sample.

The felt pad was compressed between a porous piston and septum consisting of thick, perforated brass disks faced with 150-mesh screen backed by 48-mesh screen. Two very thin brass clamping rings were installed, opposite each other, on the faces of the piston and septum to form the guarded test zone of 45.6 sq. cm. A hydraulic jack was used to apply compressive pressures ranging up to 1000 p.s.i. to the piston assembly. Provision was made to clamp the piston in place when the desired pad thickness was reached. Dial indicators attached to the piston assembly were used to measure the separation of piston and septum faces. The guard rings were removable to permit the taking of accurate zero indicator readings with the septum and piston in contact.

Prior to the permeability measurement, the felt samples were cut to the exact size of the permeability cell, cleaned and completely saturated with purified water. The water-saturated sample was then transferred to the permeability cell and compressed to the desired thickness. Flow through the sample was controlled by proper adjustment of needle valves at each pump and a clamp on the rubber inlet hose. Accurate measurement of the flow rate through the test zone was made with a rotameter and the pressure difference across the sample was obtained as the difference in the water level in an open-end manometer when no flow occurred and when the desired constant flow rate proceeded through the sample. A series of such flow rate-pressure drop measurements were obtained for each sample at several different pad densities. Pressure drop values were corrected, where necessary, for the flow resistance of the piston and septum, determined in a separate experiment. Pad decay (i.e., an increase in pressure drop across the pad with continued constant flow) was minimized by using small flow rates, reading the manometer as soon as equilibrium conditions were attained, advancing from low to high flow rates during a run, and by proceeding rapidly from flow rate to flow rate to minimize the total time that water flowed through the pad. Filtered, deionized, and deaerated water of constant temperature was used for all experimental work. The density, c, of the pad at a given sample thickness was obtained from the ovendry pad weight and the calculated pad volume.

Lateral Permeability Measurement

The lateral permeability cell, shown in Fig. 3, consisted of three main parts, namely, a head chamber, compression jaws, and a divided discharge chamber. The compression jaws, constructed of solid pieces of brass, were used to compress a 1- by $4^5/_8$-in. felt sample. Four vertical beveled ridges 1 in. long, protruding slightly above the face of each jaw, divided the flow area into a 3-in. wide center test zone and two $^1/_2$-in. wide outer guard zones. The ridges at the outside ends of the guard zones caused the felt to act as a gasket and prevented leakage. The opposing jaws operated on accurately aligned keyways, mounted in a steel framework that permitted compression of the sample by means of a hydraulic jack. Chromium-plated

steel spacers of accurately known thickness, inserted between the jaws beyond the flow area, were used to set the desired sample width.

The divided discharge chamber of brass construction was provided with two compartments—one for collection of flow from the center test zone and one for collection of flow from the guard zones. After the water-saturated sample had been compressed to the desired thickness and the jaws were locked in place, the divided discharge chamber, previously filled with water, and the brass head chamber were screwed to the bottom and top sides, respectively, of the jaw pair. Connection of the water inlet of the head chamber was made to the discharge side of the pump, and the head chamber was filled with water permitting air to leave the chamber through the petcock as the water entered. Each compartment of the discharge chamber was connected to its own separate piping system. Needle valves in each system permitted the necessary flow adjustments to keep the pressure in the two compartments equal, and prevent sidewise flow through the sample. A needle valve in the by-pass line connecting the suction and discharge sides of the pump was used in the control of flow and the pressure in the head chamber. The rate of flow through the center test zone of the sample was measured with a rotameter installed in the piping leading from this section. The pressure in the head chamber and in each compartment of the discharge chamber was measured with open-end mercury manometers. The pressure difference across the sample was the difference in pressure between the head and discharge chamber minus the difference in fluid head between the points where the pressure was measured. Readjustment of the flow-control valves permitted the determination of the pressure drop across the sample at different constant flow rates.

Fiber Diameter Measurement

Fiber cross sections when observed under the microscope, appeared closely circular and indicated that a sufficiently reliable estimate of the specific surface and specific volume of the fiber could be calculated from fiber diameter measurements by assuming a circular cross section. Fiber diameters were measured for approximately 230 water-swollen fibers from each sample at a magnification of 200×, using a compound microscope equipped with an eyepiece micrometer. To estimate the increase in fiber cross section in water due to swelling, microscopic fiber diameter measurements were made of wool fibers in the dry and water-swollen state for one sample.

Compressibility Measurement

To relate the pad density to the compressive load applied to the pad, load-deformation curves were obtained for each water-swollen felt sample with a Baldwin-Southwark Universal Tester using a compression rate of 0.0125 in. per min.

EXPERIMENTAL RESULTS AND DISCUSSION

Transverse Permeability Data

Permeability results were expressed in terms of the permeability constant, K, defined by equation (1). The permeability constant was determined at 8 or 9 pad densities for each sample from pressure drop measurements made at eight different constant flow rates. The ratio $\Delta P/q$ at each pad density was obtained as the slope of the straight line drawn through the plot of the pressure drop-flow rate data. Permeability determinations were made only at low flow rates where a good linear relationship existed between ΔP and q. A maximum Reynolds number of 0.086 was observed, which was well below Carman's (*2*) critical value of 2 defining the upper limit of the streamline flow region.

Although the manufacturing process was controlled as carefully as possible in the preparation of the felt samples, minor structural variations existed within each sample. To insure representative permeability data for each felt structure, duplicate or triplicate density versus permeability measurements were made for each sample,

Table II. Transverse Permeability Data

L, cm.	c, g./cc.	10^9K, sq. cm.	L, cm.	c, g./cc.	10^9K, sq. cm.	L, cm.	c, g./cc.	10^9K, sq. cm.
Sample 1			Sample 2			Sample 3		
0.222	0.317	176	0.222	0.316	226	0.196	0.282	435
0.203	0.348	138	0.205	0.342	173	0.180	0.307	346
0.177	0.400	91.9	0.178	0.394	119	0.148	0.373	153
0.152	0.463	52.6	0.153	0.460	66.4	0.134	0.412	91.9
0.126	0.558	20.7	0.129	0.546	30.5	0.115	0.481	44.8
0.115	0.612	10.8	0.112	0.626	14.3	0.103	0.537	25.0
0.098	0.718	4.0	0.101	0.694	7.31	0.085	0.650	10.6
0.087	0.806	2.0	0.085	0.820	2.95	0.075	0.743	5.88
						0.069	0.796	3.31
Sample 4			Sample 5			Sample 6		
0.176	0.291	362	0.228	0.304	348	0.228	0.346	210
0.153	0.336	234	0.202	0.343	224	0.202	0.390	143
0.127	0.404	118	0.178	0.390	123	0.173	0.456	78.2
0.113	0.453	66.3	0.151	0.459	58	0.147	0.537	35.3
0.101	0.507	36.9	0.127	0.546	23.8	0.121	0.653	11.4
0.088	0.585	19.7	0.113	0.613	11.3	0.108	0.730	4.27
0.075	0.688	9.45	0.099	0.702	5.16	0.099	0.798	2.45
0.067	0.768	6.35	0.088	0.792	2.79	0.089	0.883	1.52
Sample 7			Sample 8			Sample 9		
0.169	0.304	231	0.225	0.334	139	0.228	0.330	165
0.154	0.334	182	0.202	0.372	102	0.200	0.376	117
0.126	0.407	88	0.178	0.422	73.8	0.178	0.422	79
0.111	0.463	48	0.154	0.488	40.4	0.152	0.495	42.4
0.094	0.545	22.7	0.128	0.587	16.4	0.128	0.587	17.4
0.084	0.610	11.7	0.110	0.682	5.7	0.114	0.660	8.58
0.073	0.705	6.80	0.093	0.810	2.07	0.099	0.761	3.35
0.064	0.805	4.15				0.091	0.829	2.31
Sample 10			Sample 11					
0.181	0.301	340	0.203	0.293	373			
0.152	0.359	196	0.177	0.336	234			
0.126	0.433	80.5	0.153	0.379	139			
0.114	0.478	54.3	0.125	0.476	60			
0.099	0.549	32	0.111	0.536	31.2			
0.088	0.623	16.8	0.100	0.595	17.4			
0.076	0.717	8.54	0.086	0.689	7.67			
0.067	0.816	5.97	0.079	0.756	4.32			

Table III. Lateral Permeability Data

L_2, cm.	c, g./cc.	$10^9K_{2ax.}$, sq. cm.	L_2, cm.	c, g./cc.	$10^9K_{2ax.}$, sq. cm.	L_2, cm.	c, g./cc.	$10^9K_{2ax.}$, sq. cm.
Sample 1			Sample 2			Sample 3		
0.222	0.311	443	0.203	0.345	328	0.177	0.314	471
0.203	0.366	274	0.177	0.394	146	0.150	0.371	265
0.177	0.391	99.5	0.150	0.466	61.9	0.125	0.445	110
0.150	0.472	42.5	0.125	0.560	20.8	0.108	0.512	68.1
0.125	0.565	14.4	0.108	0.650	8.55	0.0987	0.564	37.3
0.108	0.658	4.97	0.0987	0.706	4.78	0.0835	0.666	12.3
Sample 4			Sample 5			Sample 6		
0.177	0.296	674	0.222	0.326	279	0.222	0.348	490
0.150	0.349	278	0.203	0.357	198	0.203	0.380	316
0.125	0.418	95.0	0.177	0.410	90.9	0.177	0.436	145.5
0.108	0.481	84.0	0.150	0.483	30.0	0.150	0.514	60.4
0.0987	0.530	49.3	0.125	0.580	13.3	0.125	0.618	19.8
0.0835	0.627	11.9	0.108	0.667	2.21	0.108	0.711	4.63
			0.101	0.715	1.17	0.0987	0.783	1.58
Sample 7			Sample 8			Sample 9		
0.177	0.296	434	0.222	0.337	362	0.203	0.373	266
0.150	0.348	209	0.203	0.368	253	0.177	0.428	121
0.125	0.419	60.0	0.177	0.423	95.5	0.150	0.504	44.5
0.108	0.481	55.9	0.150	0.498	34.8	0.125	0.605	14.2
0.0987	0.530	25.0	0.125	0.598	15.2	0.108	0.696	3.70
0.0835	0.626	7.09	0.108	0.688	2.51	0.101	0.746	1.72
			0.101	0.738	1.17			
Sample 10			Sample 11					
0.177	0.310	336	0.203	0.295	574			
0.150	0.366	179	0.177	0.338	380			
0.125	0.439	63.6	0.150	0.399	231			
0.108	0.505	45.4	0.125	0.478	106.0			
0.0987	0.556	27.1	0.108	0.551	65.7			
0.0835	0.658	4.45	0.0987	0.605	38.6			
			0.0846	0.707	9.35			

Table IV. Fiber Properties

Sample no. →	1[a]	1	2	3	4	5	6	7	8	9	10	11
Arithmetic average diameter,[b] μ	24.9	29.0	32.6	30.4	28.0	27.7	32.7	26.2	28.9	30.6	29.6	31.0
Surface-weighted average diameter,[c] μ	26.5	30.8	33.3	31.2	31.0	29.2	34.5	26.5	30.6	32.8	31.2	31.3
Specific surface, sq. cm./cc.	1510	1300	1200	1280	1290	1370	1160	1510	1310	1220	1280	1275
Yarn size, cut	16	16	16	16	16	16	11	20	16	16	16	16

Calculation of Swollen Specific Volume

Weighted-average dry fiber diameter, μ	26.5
Weighted-average wet fiber diameter, μ	30.8
Increase in cross section, %	35.2
Dry specific volume (*25*), cc./g.	0.766
Water-swollen specific volume, cc./g.	1.04

[a] Dry fiber; all other samples were water-swollen.
[b] Arithmetic average diameter = $\Sigma d/n$, where d = fiber diameter and n = total no. fibers measured.
[c] Surface-weighted average diameter = $\Sigma d^2/\Sigma d$.

using a different pad for each set of measurements. An average deviation of the mean permeability constant, at any given density, of 3 to 7% was observed for each sample. The transverse permeability results for the first pad of each sample are given in Table II.

Lateral Permeability Data

The lateral permeability results were also expressed in terms of a permeability constant defined by equation (1). In the calculation of the lateral permeability constant, designated as K_2, the bed depth, L, was a constant of the apparatus, 2.54 cm., but the cross-sectional area, A, of the pad normal to flow varied as the pad was compressed. Designating the pad thickness as L_2, the value of A was equal to the product of L_2, and the constant length of the test zone of the apparatus, 7.72 cm.

The lateral permeability was determined for flow in a direction parallel to the warp yarn, which would be in the machine direction on the paper machine. The permeability constant, K_2, was determined at several pad densities for each sample from the flow rate-pressure drop data in a manner similar to that described for the transverse permeability data. Maximum Reynolds numbers of 1.4 at the lowest pad density and 0.02 at the highest pad density were indicative of viscous flow conditions. Because the walls of the lateral permeability cell offered some resistance to flow, the experimental permeabilities were corrected for this small effect using Carman's (*2, 6*) correction factor.

Triplicate determinations of K_2 were made at several pad densities for each felt sample using a new pad for each set of flow rate-pressure drop measurements. An average deviation of the mean permeability constant, at any given density of 3 to 8% was observed for each sample. The lateral permeability results are given in Table III.

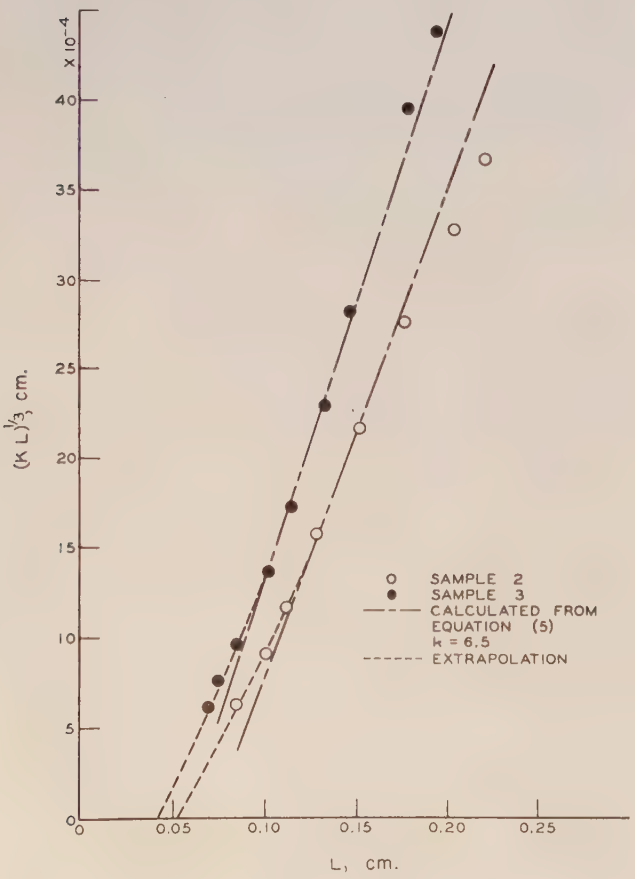

Fig. 4. Transverse permeability

Microscopic Fiber Diameter Data

The fiber diameter distributions observed for all samples were similar and were typical of wool fiber distributions reported for commercial samples of medium wool grades (*24*). The specific surface values were calculated for each sample from the individual fiber diameter measurements using the following expression (*12*)

$$S_v = 4\Sigma d/\Sigma d^2 \qquad (6)$$

where d is the fiber diameter.

The water-swollen specific volume was evaluated from the pycnometric density of dry wool (*25*) by calculating the increase in fiber cross section in water from the microscopic fiber diameter measurements of the dry- and water-swollen fibers. Because the wool fiber increases only 1% in length in water (*26*), the increased fiber volume in water is related primarily to the increase in cross section. The results of the specific surface and swollen specific volume calculations are given in Table IV.

Application of the Kozeny-Carman Equation to the Data

Graphical treatment of the transverse permeability data in the form $(KL)^{1/3}$ against L suggested by equation (5) gave a straight line over a wide porosity range for all samples. For all felts similar deviations from linearity were observed at very low porosities, and for four samples a very slight deviation from linearity was observed at the highest porosities used. The data for samples 2 and 3 are plotted in Fig. 4 which are typical of all samples in regard to the deviation of the experimental points from the predicted linear relationship. To show agreement with the Kozeny-Carman theory, the lines drawn through the linear portion of the data have been calculated from the Kozeny-Carman equa-

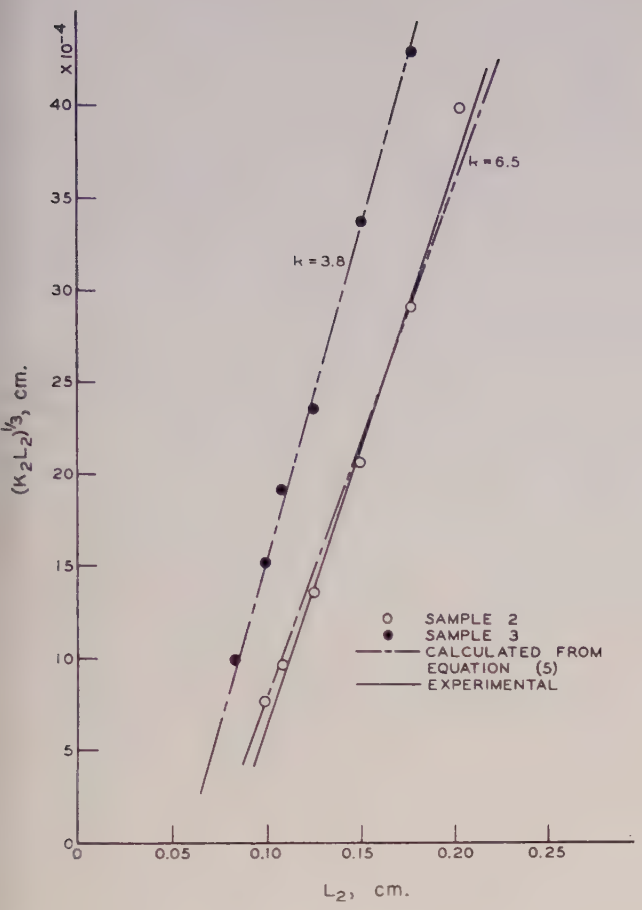

Fig. 5. Lateral permeability

tion using the swollen specific volume and the specific surface values calculated from microscopic fiber diameter measurements. As will be discussed later the Kozeny factor was taken equal to 6.5 for these samples. Because the samples differ from one another in weight per unit area and structure, data for different samples fell on separate straight lines.

If the lower curved portion of the data for each sample is extrapolated to the L-axis, the value of L_0 obtained corresponds closely to the value based on a bed density equivalent to the pycnometric density of dry wool. Thus, a change in the effective particle density from that of the water-swollen fiber at medium bed porosities to that of the dry fiber at zero porosity is indicated. It is possible that as larger and larger compressive loads are applied to the felt, the fibers are partially deswelled at points where they contact other fibers. As compression proceeds, the number of points of contact between fibers would increase until in the limiting case at zero porosity, the bed becomes a mass of solid wool with a density equal to that of the dry fiber. Maximum compressive loads of 1000 p.s.i. were applied to the pad, but locally at points of fiber contact the loading would be much greater.

A plot of the lateral permeability data for each sample in the form $(K_2L_2)^{1/3}$ against L_2 was linear over a wide porosity range. The data for samples 2 and 3 are plotted in Fig. 5 which are typical of other samples in regard to the deviation of the experimental points from the predicted linear relationship. To show agreement with the Kozeny-Carman equation, lines calculated from the equation using the swollen specific

Table V. Transverse Permeability Porosity versus Kozeny Constant

v = 1.04 cc./g., assumed constant

ϵ	k	ϵ	k	ϵ	k	ϵ	k
Sample 1		Sample 2		Sample 3		Sample 4	
0.671	9.2	0.672	8.6	0.708	5.8	0.698	6.3
0.639	8.5	0.645	8.5	0.681	5.5	0.652	6.0
0.587	7.5	0.591	7.2	0.613	6.1	0.581	5.8
0.520	6.8	0.525	6.6	0.572	6.8	0.530	6.3
0.421	6.3	0.434	5.7	0.500	6.8	0.474	6.3
0.365	6.3	0.350	5.0	0.442	6.7	0.394	5.2
0.255	4.4	0.280	3.5	0.325	4.3	0.286	3.0
0.164	1.8	0.149	1.1	0.230	2.1	0.204	1.3
				0.174	1.4		
Sample 5		Sample 6		Sample 7		Sample 8	
0.684	4.9	0.640	7.1	0.684	6.0	0.654	9.7
0.644	5.0	0.595	6.7	0.654	5.6	0.614	8.8
0.595	5.4	0.526	6.2	0.578	5.4	0.562	7.2
0.524	5.7	0.463	7.2	0.520	5.5	0.494	6.7
0.433	5.6	0.324	4.9	0.435	4.5	0.390	5.6
0.364	5.6	0.243	4.3	0.366	4.2	0.292	5.1
0.271	3.9	0.172	2.3	0.269	2.3	0.160	1.6
0.178	1.6	0.082	0.2	0.165	0.7		
Sample 9		Sample 10		Sample 11			
0.658	10.2	0.688	6.0	0.696	6.1		
0.610	8.8	0.628	5.5	0.651	5.9		
0.562	8.0	0.550	6.2	0.606	6.4		
0.486	7.1	0.504	5.8	0.505	5.4		
0.390	6.3	0.431	4.7	0.444	5.5		
0.315	5.4	0.354	3.8	0.383	5.2		
0.210	3.1	0.255	2.1	0.285	3.6		
0.140	1.1	0.150	0.2	0.215	2.3		

volume and specific surface values given in Table IV have been drawn through the data points. For reasons to be explained later the Kozeny constant was taken as 6.5 for sample 2 and 3.8 for sample 3.

Although a comparison of the results of this investigation with those of Ginn (*22*) would be interesting, one is not given because the proper basis for the comparison is not clear. Ginn's porosity values for his water-permeability studies were not corrected for the change in fiber volume caused by swelling and the rather large differences reported between the air and water-permeability characteristics of the same sample raise a doubt as to the proper permeability characteristics to use for comparison purposes.

Effect of Felt Structure on Permeability

The fit of the permeability data for all samples to the Kozeny-Carman equation was very good, indicating that deviations of the felt structure and flow mechanism from the assumed bed structure and flow mechanism upon which the Kozeny-Carman theory is based are not serious enough to invalidate the theory for the analysis of viscous flow through woven felts. Thus, for woven felts under compression, the concept of capillary flow through interfiber pores is basically correct, and consideration of the relative importance of interyarn and interfiber flow is not necessary. To evaluate the contribution of the woven structure to the fiber orientation affecting flow, the orientation-dependent Kozeny factor was calculated at several pad densities for each felt and compared with values reported by others for fibrous beds of known orientation. Because the permeability of the felts in the lateral direction is quite different from their permeability in the transverse direction, the two will be discussed separately.

Effect of Transverse Direction

For each sample the Kozeny factor was evaluated at several pad densities from equation (2) using the specific surface values calculated from fiber diameter measurements and the porosity evaluated from equation (3) using the water-swollen specific volume (1.04 cc./g.) for

v. The calculated values of k are given in Table V. At low porosities unreasonably small calculated values of k and porosity are obtained when v is assumed constant. From geometrical considerations the small calculated values of the porosity obtained are very unlikely, and it seems more probable that the effective specific volume decreases, as discussed above.

For most samples an average value of 6.5 was observed for the Kozeny factor over the porosity range 0.4 to 0.7. For samples 5, 7, and 10, an average value of 5.4 seemed more probable. Most samples, therefore, must be characterized by a fiber orientation primarily perpendicular to flow. The orientation in samples 5, 7, and 10 tends to be more random. The duplex weave of samples 5 and 10, characterized by more entwinement of the fill yarns around the warp yarns than the other weaves, would be expected to present the more random fiber orientation. Sample 7, having the smallest fiber and yarn size, is probably more easily deformed under load and assumes a more randomized fiber orientation. Because the Kozeny factor remains relatively constant in the porosity range 0.4 to 0.7, a change in the effective fiber orientation, and thus in k, at lower porosities is unlikely. Although a gradual decrease in k with porosity has been predicted and observed by others, as discussed previously, the precision of these data is not good enough to indicate such a trend. The effective specific surface probably remains relatively constant also, because any increase in S_v due to a deswelling of the fiber would be offset by a simultaneous increase in the area of fiber-to-fiber contact. Therefore, in the lower porosity region, the Kozeny factor and the effective specific surface probably do not change greatly, but the effective specific volume varies significantly.

The data for samples 2 and 7, and 6 and 3 may be compared to observe the effect of yarn size on permeability. The first sample in each pair has a larger yarn size but is otherwise similar to the second sample. Sample 7 is characterized by a slightly more randomized fiber orientation than sample 2, but no difference is observed between the effective fiber orientation of samples 6 and 3. Because the average fiber diameter of sample 7 is smaller than all other samples and is about 20% less than that of sample 2, whereas the average fiber diameters of sample 3 and 6 differ by only 10%, the more randomized fiber orientation of sample 7 is more likely related to its difference in fiber diameter instead of its yarn size.

A similar comparison of the data for sample pairs 1 and 8, 2 and 9, and 3 and 11 indicates no difference in the permeability characteristics between the napped and unnapped felts. Evidently, the fiber ends teased from the fill yarns in the napping process resume an orientation normal to flow when a compressive load is applied or flow is initiated. Also, the number of fibers affected by the napping operation is probably so small in comparison with the total number of fibers in the pad that any change in their orientation is not detected. The unimportance of napping to the permeability further emphasizes the importance of interfiber rather than interyarn flow in woven felts. If interyarn flow were important, the raising of individual fibers from the yarn surface would be expected to change the permeability.

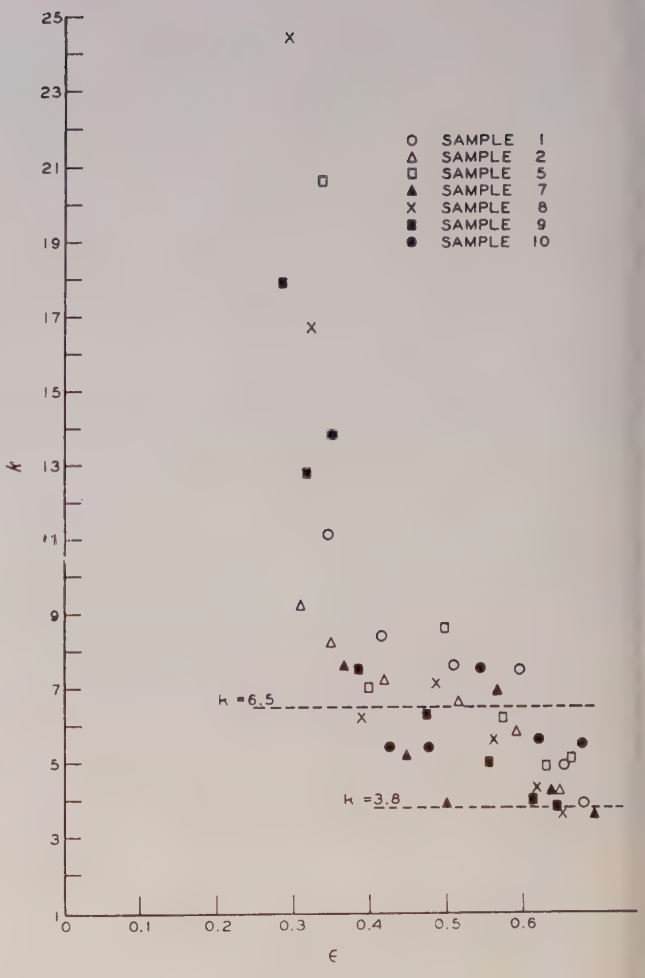

Fig. 6. Lateral flow variation k with ε

Effect of Lateral Direction

In the evaluation of the Kozeny factor at different pad densities for lateral flow, the effective specific volume at low porosities was corrected for the deswelling observed under large applied compressive loads. Specific surface values determined from the microscopic fiber diameter measurements were used in the calculations.

The data revealed a strong dependence of the Kozeny factor upon the weave pattern and the number of fill yarns per inch. (The number of warp yarns per inch was constant at 48 for all samples.) The variation in Kozeny factor with porosity was similar for all samples having 70 fill yarns per inch and for sample 10 which had 48 fill yarns per inch but a duplex weave. The data for these samples are plotted in Fig. 6. The variation in k with porosity was similar for all samples having 48 fill yarns per inch and the plate or sateen weave, but differed from the variation of the other samples. The data for the latter group are plotted in Fig. 7.

For all samples the warp yarns are oriented parallel to the flow direction. Therefore, a certain proportion of the total flow would be expected to proceed parallel to these yarns and to the fibers in them. It will be recalled from the work of others (*14*, *15*) that the value of the Kozeny factor is extremely sensitive to the degree of parallelism of the fibers and the porosity for flow parallel to the fiber axes. Therefore, small variations in fiber orientation would be expected to have a more

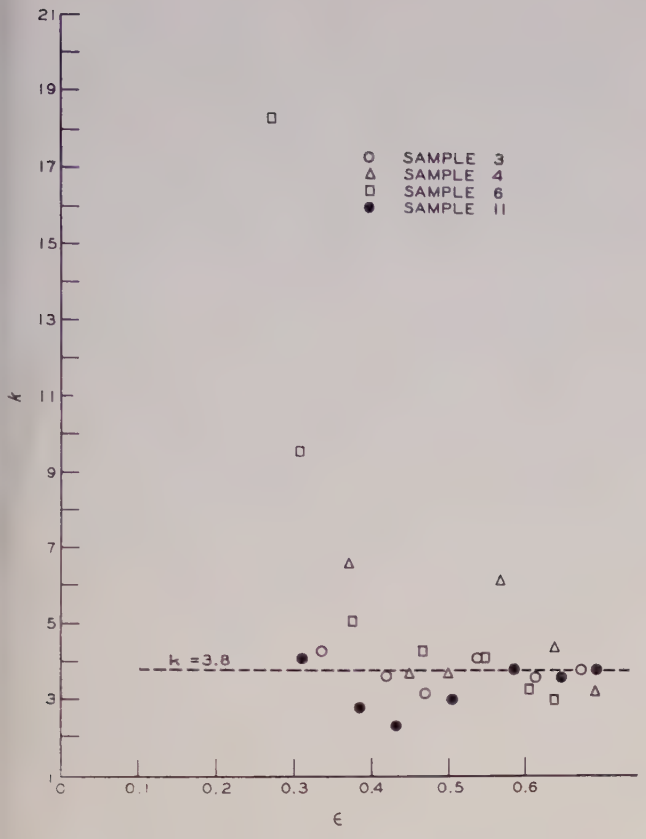

Fig. 7. Lateral flow variation k with ϵ

noticeable effect on lateral than on transverse permeability.

The calculated value of the Kozeny factor is an average value based on the proportions of the total flow proceeding parallel to and normal to the fiber axes, and, therefore, will indicate the predominant flow pattern. Referring to Fig. 7, those samples having an equal number of fill and warp yarns per inch and a plate or sateen weave, are characterized by a predominance of flow parallel to the fibers in the warp yarns as evidenced by the low, constant average value of k of 3.8 in the porosity range 0.3 to 0.7. Because the Kozeny factor does not decline with porosity as has been observed for perfect parallel flow conditions (*14*), the parallel flow pattern must be gradually altered with compression.

Referring to Fig. 6, those samples having 70 fill yarns per inch and the plate or sateen weave are characterized by a predominance of flow parallel to the fiber axes at high porosities (0.6 to 0.7) as indicated by an average k of 3.8. The flow pattern changes to a predominance of flow normal to the fiber axes in the porosity range 0.3 to 0.6 as indicated by an average Kozeny factor of 6.5. The larger number of fill yarns per inch not only constitute the greater portion of the total pad volume, but upon compression they must distort the warp yarns sufficiently to produce an effective fiber orientation more nearly normal to flow.

Samples 5 and 10 (Fig. 6), having the duplex weave, are characterized by an average value of k of 6.5 in the porosity range 0.3 to 0.7. The greater entwinement of the fill yarns about the warp yarns in the weave pattern must produce a fiber orientation more normal to flow even under very small compressive loads.

All samples were characterized by an apparent increase in the Kozeny factor at porosities of 0.3 to 0.35. Calculated values of k as large as 26 were observed. Assuming an average value of 2.5 for the shape factor, k_0, a tortuosity $(L_e/L)^2$ of about 10 would be indicated. Carman (*6*) has argued that (L_e/L) should be about 1.5 for unconsolidated porous beds. A tortuous path about 50% longer than the bed depth seems logical, but a tortuous path over three times as long as the bed depth ($L_2/L = \sqrt{10}$) does not seem realistic. In the calculation of k it was assumed that all of the void space in the felt was equally available to flow. However, in the lateral direction some of the void space probably becomes unavailable to flow when the felt is under high compression, and the effective porosity is less than that used in the calculations. In that case the calculated value of k would be too large.

Since the above effect was not observed for transverse permeability under large compressive loads, the differences in effective fiber orientation in the two directions are probably responsible for the effect. As the felt is compressed, the fibers in each yarn probably slip into pore spaces between other fibers, because the fibers in each yarn are generally parallel to each other. Where fibers cannot slip between other fibers, they would be deformed and deswelled as they contact other fibers. Because fill and warp yarns are perpendicular to each other, a gridlike orientation of the fibers would be formed for transverse flow. Viewing the felt from the lateral direction, the perpendicular fill yarns are flattened out and the individual fibers tend to slip behind one another. Pore spaces between these fibers would become partially unavailable to lateral flow. Areas of fiber-to-fiber contact also increase with compression, perhaps reducing the void area at some sections and increasing the amount of unavailable pore space.

From the above discussion the influence of the weave pattern and the number of fill yarns per inch on the lateral permeability were observed to be significant. The influence of yarn size and napping on lateral permeability was not important, however. Although the larger yarn size of sample 6 gave it a weight per unit area nearly the same as those samples with 70 fill yarns per inch, its lateral permeability characteristics were similar to those samples having a smaller weight per unit area but the same number of fill yarns per inch. Likewise, sample 7 had a smaller weight per unit area than other samples with 70 fill yarns per inch, but its lateral permeability characteristics were similar.

Compressibility Data

The compressibility of all felt samples could be represented by the empirical equation

$$c = MP^N \qquad (7)$$

where c is the apparent pad density, P is the applied load and M and N are experimentally determined constants. The values of these constants are given in Table VI.

The values of M and N were observed to differ slightly for each sample indicating a dependence of the compressibility upon the fiber orientation. Van Wyk (*27*) and more recently Wilder (*28*) imposing some severe restrictions on the structure of a fibrous mat have related the constants M and N to certain properties of the fiber and the mat. Assuming that the deformation is the result only of fiber bending and that the beam equations can be applied to the fibers, N was shown to

Table VI. Compressibility Constants for the Equation, $c = MP^N$

c, g./cc.; P, kg./sq. cm.

Sample no.	*M*	*N*
1	0.365	0.194
2	0.351	0.205
3	0.342	0.214
4	0.372	0.208
5	0.375	0.221
6	0.364	0.200
7	0.340	0.201
8	0.386	0.196
9	0.360	0.205
10	0.358	0.218
11	0.343	0.216

depend only on the unsupported fiber length and M was dependent on the fiber properties. Because the fiber orientation differed from sample to sample, the variation in N would be expected. The importance of fiber orientation to the value of N may be observed from the data for sample pairs 1 and 8, 2 and 9, and 3 and 11. The samples in each pair have the same structure and differ from each other only in the presence or absence of a napped surface. From Table VI it is seen that the two samples of each pair have closely the same value of N. In these samples and others where the value of N is the same, the observed value of M does not appear to be in accordance with the predictions of the above theory, however. Thus, the theory may not apply for the compression of these samples. A major reason for nonagreement may be the importance of fiber slippage in felt compression, a mechanism not considered in the above theory.

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Stainless Steel Weld Metal Overlay Linings for Pulp Digester Vessels

K. L. CROOKS and G. E. LINNERT

A number of kraft pulp digester vessels equipped with linings of stainless steel applied by the weld overlay method unexpectedly have shown accelerated corrosive attack. Samples from a number of overlay lined pulp digester vessels which suffered accelerated corrosive attack have been examined and analyzed. A preponderance of evidence shows the principal corrosion to be attributable to two clear-cut conditions; namely, (1) small areas of low-alloy content (heterogeneity) dispersed throughout the overlay lining, and (2) frequently, a low average level of alloying elements in the lining. The heterogeneity, detected initially by localized differences in microstructure, is evaluated quantitatively by chemical analyses made with the electron microprobe. Attack by the pulp liquor is shown to be concentrated on the areas of low-alloy content. Galvanic action between the high and low alloy areas in close proximity may increase the rate of attack. Hot cracks or microfissures are present occasionally, and where exposed at the lining surface provide an inroad for the pulp liquor to reach low-alloy areas in the weld bead interior. Other than this function, the hot cracks do not appear to incite corrosive attack. The heterogeneous, low-alloy condition apparently results from unsatisfactory welding technique. Preliminary experiments already suggest travel speed to be an important factor in welding technique, and that high speeds lead to composition heterogeneity. The welding wire compositions employed in this work are discussed, and consideration is given to the development of an improved welding wire alloy designed specifically for the digester vessel application.

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This paper deals with an examination of stainless steel linings formed by depositing weld metal on the inner surface of kraft pulp digester vessels. The paper industry resorted to widespread use of these linings to combat corrosion of the digester shells about 10 years ago. These large vessels ordinarily were constructed of carbon steel and were expected to have a service life of 10 to 20 years. However, a steady upward trend in pulp cooking temperature, liquor concentration, and other pulping conditions caused increased metal loss from the digester walls. Some vessels would not comply with code and insurance requirements after only 2 to 4 years of service.

Various methods of providing a stainless steel lining for vessels already in service have been explored. These include the use of sheet attached by plug and seam arc-welding to the carbon steel vessel wall, the application of narrow strip by seam welding in similar fashion, and the deposition of overlapping beads of weld metal to form an overlay on the inside surface. Installations of sheet or strip linings are reported to be not entirely satisfactory because of buckling of the lining with changes in temperature, joint breakage, and stress-corrosion cracking at weld joints. Weld overlay lining usually consists of a single layer of weld metal although occasionally two layers are applied for various reasons. Although the deposition of overlapping weld beads to form a continuous lining would seem to be quite costly and time consuming, this overlay method has developed into an economical operation for extending the useful life of vessels.

Alloy Selection

Most weld overlay linings have been made by depositing a single layer with E-310 stainless steel welding wire, a standard austenitic (nonmagnetic) alloy containing about 27% chromium and 20% nickel. A few early attempts were made to employ weld wire types containing lower alloy content, like E-308, E-316, but these overlay linings either exhibited accelerated corrosive attack or were deficient in ductility and touchness. These failings were assumed to be caused by a low level of alloy content in the overlay. The E-310 electrode wire appeared to have a sufficiently high total alloy content to tolerate considerable pickup of the carbon steel base plate and still provide a tough, austenitic weld overlay with good corrosion resistance. More recently in the overlay activity, some use has been made of Type 316 welding wire along with additional alloy introduced through a weld flux and also a modified Type 310 welding wire containing about 2% molybdenum. The reasons advanced for employing the Cr-Ni-Mo compositions will be described later in this paper. While pulp mill records usually indicate the grade welding wire employed in repair operations on each digester vessel, little attention has been given to the actual chemical composition and metallurgical nature of the weld metal overlay.

Welding Processes

The earliest weld metal linings were applied manually by the metal-arc process using flux covered electrodes. As the areas requiring overlay became larger, some form of automatic welding was necessary to minimize costly down time and to avoid the usual shortcomings in weld quality which are attributable to operator-fatigue. Two different automatic welding processes have been employed for large-scale application of the Type 310 weld metal overlay. One, the submerged-arc process, uses a bare consumable electrode wire with a granulated flux which melts and shields the weld deposit. The second, the inert-gas shielded consumable metal-arc process, makes use of a small diameter, bare electrode which is protected by an inert gas atmosphere during welding. All three processes, (1) metal-arc manual, (2) submerged-arc, and (3) inert-arc, are suited for the deposition of stainless steel weld metal.

Character of Weld Metal Overlay

The metallurgical characteristics of weld overlay linings fused by any one of the three popular processes

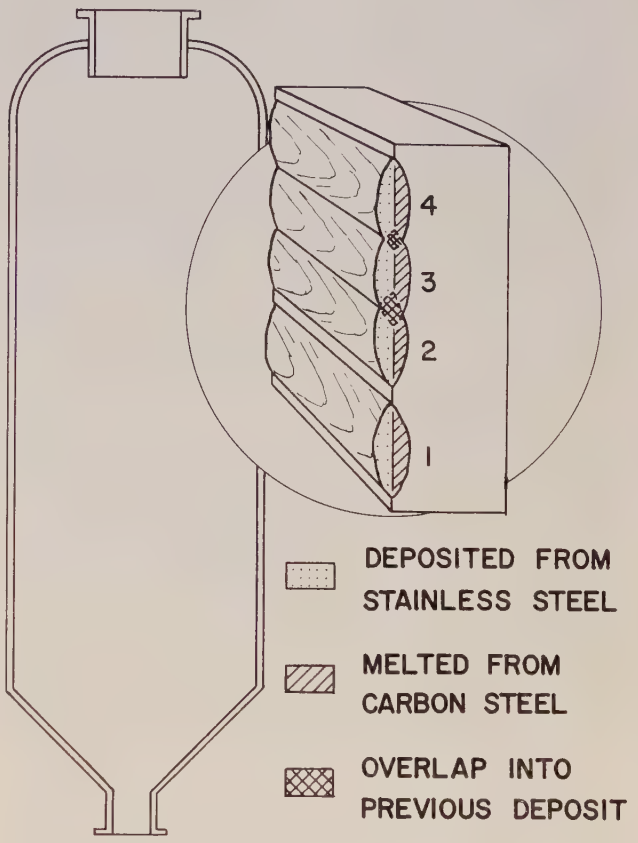

Fig. 1. Schematic illustration of digester vessel with enlarged insert showing relative proportions of stainless steel electrode wire and carbon steel base metal which form the weld bead

are quite similar. Only the mechanics of the individual methods cause variations in weld bead contour, width, cross-sectional area, and appearance.

Probably the most obvious characteristic common to all three processes results from the mixing which occurs when the melted portion of the carbon steel base plate commingles with the stainless steel deposited from the electrode wire (and possibly some alloy contributed by a flux). The stainless steel is diluted, and the total alloy content of the resultant weld bead is less than that of the original E-310 weld wire. Dilution values are a

function of the relative proportions of stainless steel and mild steel which from the molten weld puddle. Figure 1 is a schematic illustration of the proportions of stainless steel, carbon steel, and previously deposited weld metal that makeup each weld bead in a typical overlay. The plain steel that enters the weld deposit contains negligible amounts of alloying elements (other than carbon) and therefore is looked upon as diluting the stainless steel weld deposit. Dilution (usually expressed as the percentage of base metal which enters the weld deposit) is not a fixed factor, but can be made to vary over a considerable range by changing the technique or conditions used with each of the various welding processes.

A fact deserving of emphasis is that, although materials of three different compositions are melted to form the weld metal, under regular welding conditions the solidified deposit will be of uniform chemical composition throughout its mass. Sufficient electro-magnetic stirring action ordinarily occurs in the molten pool under the arc to produce a homogeneous alloy melt. After solidification, chemical analyses ordinarily

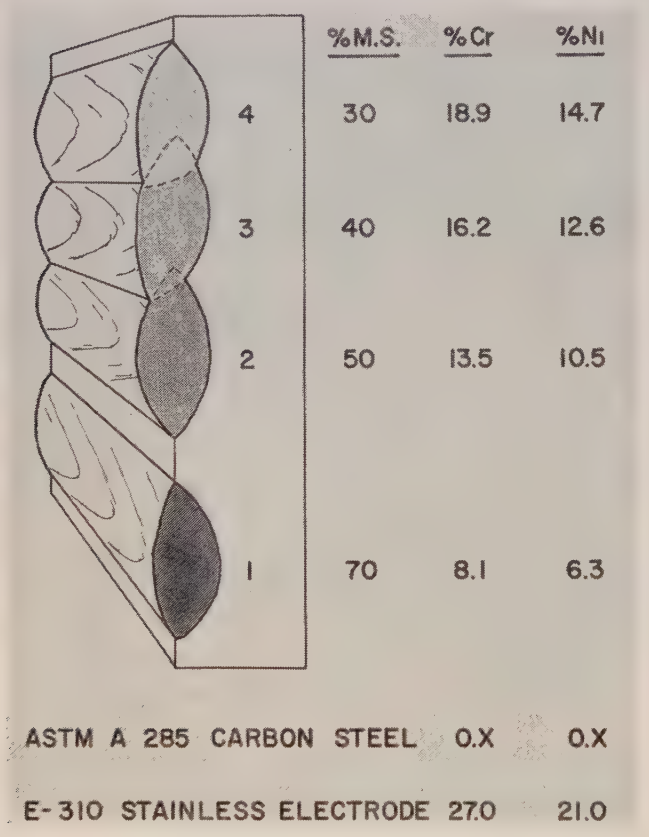

Fig. 2. Representation of variations in dilution (% M.S.) as a result of differences in weld penetration and weld bead overlap

will disclose no significant variation in composition of the bead from side-to-side or from top-to-bottom. The only composition difference which would be expected to appear is a very narrow zone of diffusion between the high-alloy weld deposit and the low-alloy base metal. Here, on a microscopic scale, evidence of alloy diffusion into the base metal and carbon migration into the weld deposit regularly can be seen. However, this diffusion occurs immediately after the deposit has solidified and is confined to the very narrow zone adjacent to the base-weld interface.

Figure 2 is intended to portray, therefore, that an overlay of weld beads would be expected to have an alloy content somewhat lower than the weld wire employed. However, each bead normally would be uniform in chemical composition. Furthermore, little variation in composition should occur from bead-to-bead unless the extent of base metal melting varied because of changes in overlap or other welding conditions that affect weld penetration into the base metal. The four weld beads comprising the overlay in Fig. 2 illustrate the composition changes to be expected with variations in dilution (% M.S.). Dilution obviously is determined by the mode of deposition of each bead and its penetration into the previously deposited bead and the base metal.

Weld metal deposited from an E-310 electrode on carbon steel base plate would be expected to display a wholly austenitic microstructure. However, if the dilution exceeded about 55%, the alloy content of the weld metal would be too lean to maintain the soft, tough austenitic structure and transformation to the harder, less-ductile martensitic structure would occur. Since dilution can be maintained well below 50% with a number of welding processes, austenitic stainless steel overlay has been applied for corrosion protection on many different kinds of pressure vessels and chemical processing units. The reliability of these overlay linings is attested by their use on the inner surfaces of the main containment vessel for nuclear reactors of the pressurized water type.

Occurrence of Overlay Corrosion Difficulty

Early in 1959, the authors' attention was directed to reports of corrosion which occurred unexpectedly in stainless steel weld overlay linings on pulp digester vessels. The number of vessels displaying corrosion difficulty appeared to be small relative to the great number which were operating successfully with weld overlay linings. However, even these limited reports of difficulty caused considerable concern among maintenance engineers, since many engineers were contemplating extensive use of stainless steel weld metal linings. Each weld-applied lining represented a substantial investment which was justified mainly by an anticipated long, trouble-free service life.

Because these reports of corrosive attack were so incongruous with the usual performance of stainless steel, an investigation was organized to (1) determine the cause of accelerated or damaging corrosive attack in the vessels in question, (2) examine overlay linings in digester vessels showing acceptable performance to discern any differences in the nature of the overlay, and (3) decide whether any changes were required in vessel preparation, welding electrode wire grade, welding technique, process, or procedure. The help of a number of pulp producers, weld overlay fabricators, vessel insurance, and inspection agencies was solicited in order to conduct this investigation. A number of field inspections were made; but more important, approximately 35 samples were obtained for laboratory study. These represented plugs trepanned from the shells of digesters having either satisfactory or unsatisfactory overlay linings, weld coupons prepared to illustrate the various

methods of application, and samples of the same overlay taken before and after service. The specimens were studied by metallographic techniques and were analyzed by chemical, spectrographic, or electron microprobe methods.

RESULTS OF LABORATORY INVESTIGATION

Examination of specimens from overlay in regular service, along with observations made in the field, showed that, with only a few exceptions, serious corrosive attack took place in three particular forms; viz:

1. Furrows or grooves, often quite deep and lengthy, commonly located in the approximate center of the weld beads.
2. Localized attack on restricted, distinct areas, for example, the exposed surface of a single weld bead.
3. Heavy attack on the mild steel base metal at the edge of the weld overlay or within the overlay at places where weld beads failed to overlap.

Furrow Corrosion

Furrow type corrosion appeared to be, by far, the most serious attack which occurs in stainless steel overlay. When viewed macroscopically, furrow corrosion took the form of deep grooves which extended along the bottom edge of weld beads and approximately in the center of the previously deposited bead. In most overlay processes, the weld beads are "shingled up" or proceed from the bottom to the top of the vessel. Each successively deposited bead overlaps the previous or adjacent weld bead and forms an overlapping junction. The grooves generally developed at this junction line, but extended into the central areas of the previously deposited (lower) bead.

Furrow attack varied both in the length of individual grooves and in the frequency of appearance within a digester. Cases were found where every bead within a given area showed furrows, where every other bead exhibited attack, and also were only isolated grooves appeared.

Localized Attack on Individual Weld Beads

Localized attack along the exposed surface of individual beads was a second distinct mode of corrosion. With local attack, the entire crown of a weld deposit often corroded uniformly and receded below the general surface level of the original overlay. Corrosion of the entire weld bead surface did not proceed as rapidly as furrow attack but often occurred in the same areas as furrow corrosion. Sometimes, only the junction area of overlapping weld beads exhibited good corrosion resistance and jutted above the corroded surface of the weld bead interior quite noticeably.

Attack at Skips, Voids, and Dissimilar Metal Junctions

The most easily-explained type of corrosive attack occurred where a skip or failure to overlap weld beads existed. Here, heavy rust coloration signaled a definite lack of protection. The exposed area of mild steel in close proximity to high alloy overlay undergoes rather rapid, localized corrosion (galvanic attack). Manual metal-arc overlays appear to be most prone to "skips" because of operator fatigue. None of the automatic weld overlay samples secured for examination displayed "skips" in the cladding; although the furrow corrosion had been erroneously diagnosed by a number of vessel owners as attack on areas not properly overlapped.

Corrosive attack also has been prevalent on the mild steel in a zone immediately adjacent to the edge of stainless steel overlay. Here again, the attack appears to be attributable to galvanic action.

Metallurgical Conditions Associated with Corrosive Attack

Certain microstructural and chemical conditions were found to be consistently associated with the two most serious forms of corrosion observed on overlay linings, that is, (1) furrow corrosion and (2) localized attack on individual beads. The metallurgical conditions observed were unusual for weld metal overlay deposited from E-310 electrode wire (and assumed to contain about 18% Cr and 14% Ni in the overlay), and therefore were quite unexpected. However, subsequent review of the weld metal deposition or overlay fabricating practices employed quickly explained their occurrence.

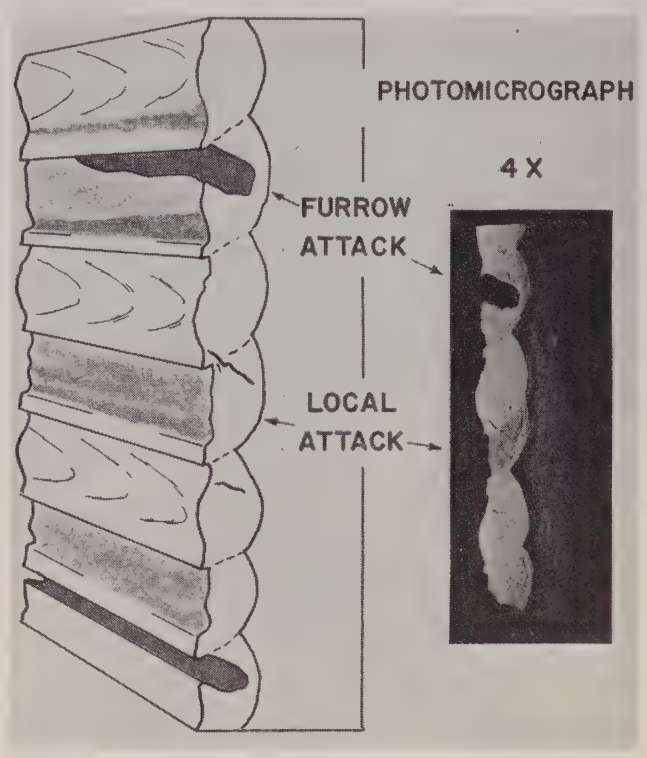

Fig. 3. Accelerated corrosive attack on a stainless steel weld overlay lining in a kraft pulp digester vessel after 18 months' service. Localized or furrow attack occurs on weld beads displaying rapid-etching (lean alloy) structure. Deposited by submerged-arc process—E-310 electrode

Heterogeneous Weld Structure

The first abnormal metallurgical condition was discovered during metallographic examination of weld overlay linings which displayed unsatisfactory corrosion resistance. Substantial areas which etched more rapidly in the metallographic reagents were observed in the weld beads. Furthermore, the majority of these areas were noted to contain varying amounts of transformed structure (martensite). The remainder of the weld structure consisted of a normal austenitic matrix with occasional chromium carbides precipitated in the austenite grain boundaries. The martensite was easily

identified by its acicular (needlelike) appearance and higher microhardness readings in contrast to the smooth-etching, softer austenite. The presence of martensite was cause for concern, not because of its higher hardness or lower ductility, but because this structural constituent indicated a significantly lower level of alloy content in the localized area. Under the welding conditions employed in depositing the overlay, martensite would be expected to appear only if the alloy content were below approximately 13% chromium and 8% nickel.

More important, the damaging corrosive attack on the surface of the overlay invariably was closely related to areas which were rapid-etching in the metallographic etchant and generally were martensitic in appearance. While the martensitic areas at first glance appeared to be distributed sporadically, a rough pattern of distribution eventually was seen in individual weld beads. For example, overlay samples which display furrow attack

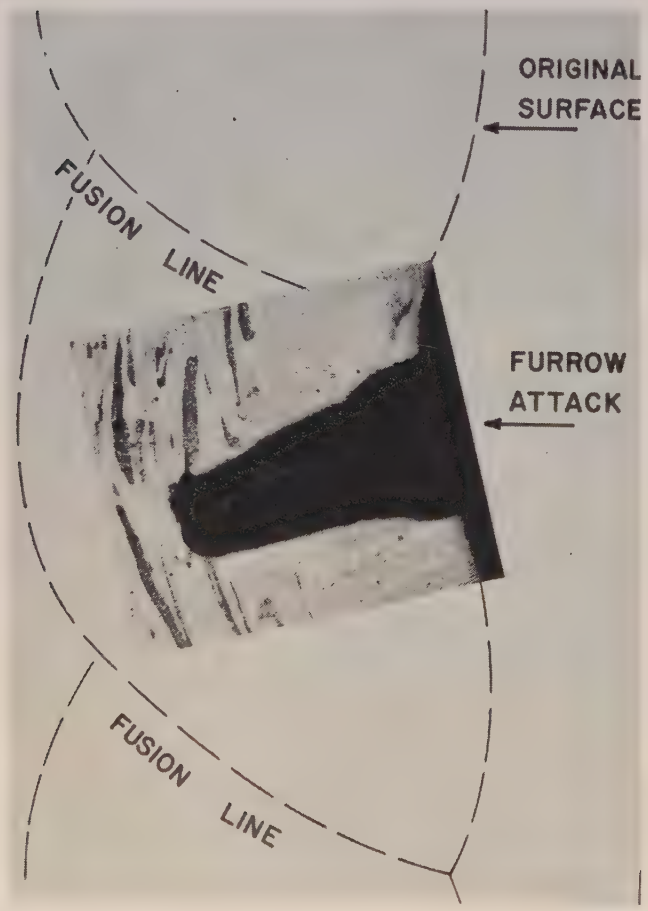

Fig. 4. Section of overlay showing a typical furrow penetrating into the center of a heterogeneous austenite weld deposit. Note preferential attack progressing along dark-etching areas

only on alternate weld beads were found to have marked heterogeneity in these same alternate weld beads. It appeared that two welding torches had been employed in tandem to deposit the overlay and one torch was adjusted in a particularly unfavorable manner for producing the overlay. Other patterns of heterogeneity in the overlay invariably were related to the individual beads.

Figure 3 illustrates an overlay that has suffered both furrow attack and localized corrosion on individual weld beads. The transverse section prepared for metallographic examination shows reasonable overlap at every junction. The stainless steel lining has not been penetrated to the carbon steel at any point. Two small hot cracks or microfissures can be seen as internal defects. The furrow attack is centered upon weld beads that display localized areas of rapid-etching or martensitic structure; with the further possibility of a hot crack having aided its penetration into the lining. The local attack on individual weld beads also has occurred

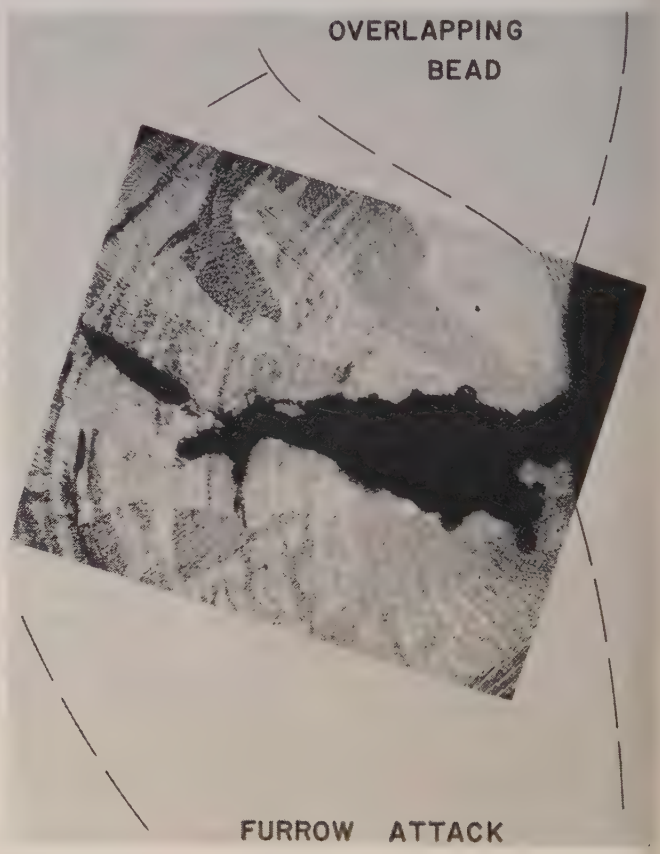

Fig. 5. Furrow attack within the central portions of a bead displaying heterogeneous austenitic weld microstructure. Penetration appears to have been aided by the presence of a hot crack

where the rapid-etching microstructure is widely prevalent throughout the bead.

Figures 4 and 5 are additional illustrations of furrow attack and the heterogeneous structure associated with this form of corrosion failure. Figure 4 shows a wide, deep furrow which is continuing to penetrate the overlay via sharply defined areas of dark-etching (martensite) structure. Figure 5 shows a more ragged furrow which also is progressing along larger areas of dark-etching structure. Some evidence here suggested that a hot crack may have been present at the surface and assisted penetration by the pulp liquor.

Level and Distribution of Alloy Content

The second unfavorable condition found in weld beads which made up the corroded overlay linings can

be described as low-level, nonuniform alloy distribution. While early reports on chemical composition suggested that overlay linings contained adequate alloy content for good corrosion resistance, these limited determinations had been made on sample chips taken from areas which encompassed a number of weld beads. Thus, an individual bead could be seriously deficient in alloy content and yet influence very little the chemical determinations on an ordinary sampling of many beads. Furthermore, the metallographic findings suggested that sampling a single, but entire, weld bead would not truly indicate the composition of localized areas within the bead that appeared different in etching characteristics and microstructure.

The electron microprobe analyzer provided a clearer picture of the nature of overlay linings which suffered attack. This instrument was employed to determine the chromium and nickel contents of a number of normal areas and of dark-etching areas in the microstructure of weld beads. Both nickel and chromium were found to change abruptly from one area to another as the microprobe traversed the metallographic specimens analyzing points about one or two microns

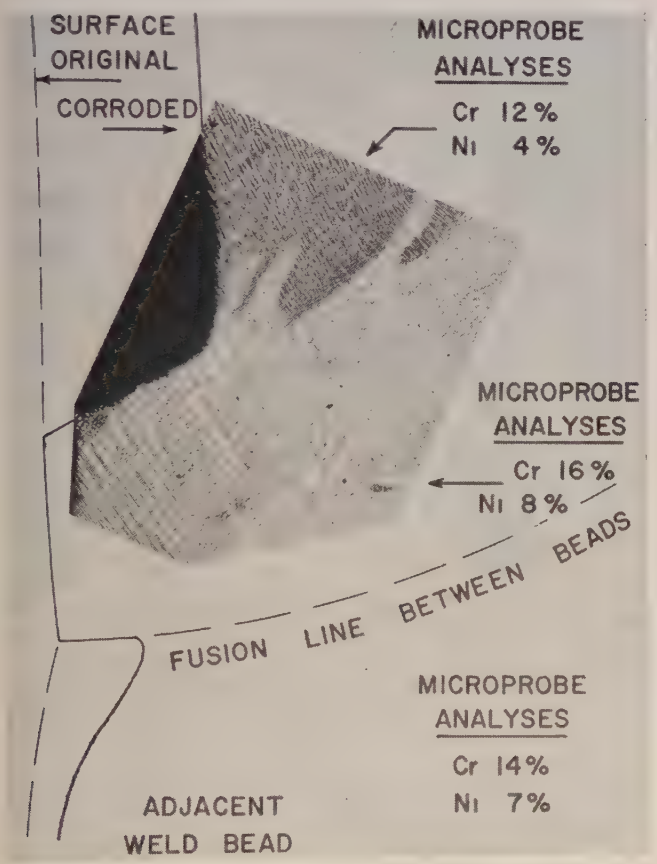

Fig. 6. Enlarged view of local corrosive attack along the surface of overlay shown in Fig. 3. Microprobe analyses reveal chemistry differences within individual beads and from bead to bead

in diameter. In every instance, light-etching austenitic areas which displayed no unusual attack from the pulp liquor were found to have a higher level of alloy. These satisfactory areas contained approximately 16 to 22% chromium and 8 to 12% nickel. On the other hand, the dark-etching areas were shown to contain chromium in the vicinity of only 12%, and nickel contents as low as about 4%.

Figure 6 portrays the chemical and structural conditions existing over a portion of the overlay illustrated earlier in Fig. 3. The bead which suffered local attack (dark-etching, martensite) is shown to contain only about 12% Cr and 4% Ni. The lighter-etching portion along the lower edge of the same bead is shown to contain 16% Cr and 8% Ni, which would account for its austenitic structure and better corrosion resistance. The adjacent bead (previously deposited) which has been moderately attacked by the pulp liquor contains about 14% Cr and 7% Ni.

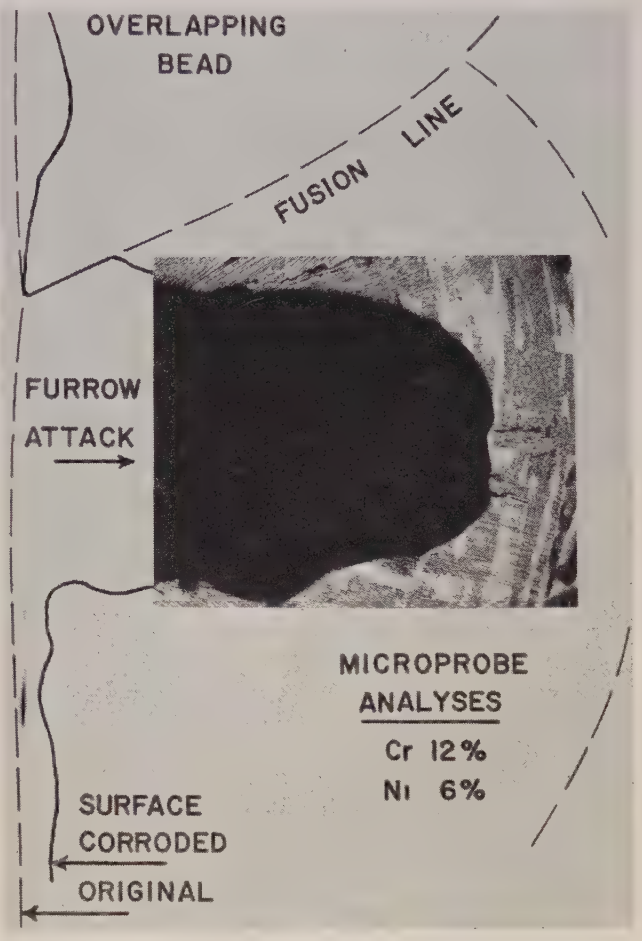

Fig. 7. Magnified cross section of overlay containing furrow attack. Corrosion occurs along the fusion line of the overlapping bead, but is confined to the central areas of the adjacent deposit. Metallographic examination shows a heterogeneous austenite microstructure. Microprobe analyses indicate lowered chemistry values in these regions

Figure 7 is an enlarged view of the furrow attack illustrated earlier in Fig. 3. The photomicrograph at 50× shows more clearly the heterogeneity in the weld structure. The microprobe has determined that the dark-etching metal into which the furrow has progressed contains about 12% Cr and 6% Ni. Traces of microfissuring can be seen at the root of the furrow and adjacent to the upper side. This cracking would have

been present after welding and may have played a secondary role in the corrosion mechanism by providing an easy inroad for the pulp liquor. Just below this dark-etching portion of metal shown in Fig. 7, a light-etching, austenitic area was found by the microprobe to contain 20% Cr and 10.5% Ni. This area possessed substantially better corrosion resistance as evidenced by its protrusion above the corroded surface. Immediately adjacent (and below) this area, corrosive attack again was more severe on metal which analyzed 15% Cr and 7.7% Ni by the microprobe.

Figure 8 illustrates localized attack in an early stage at a weld bead junction where a substantial difference in chemical composition exists. A previously deposited

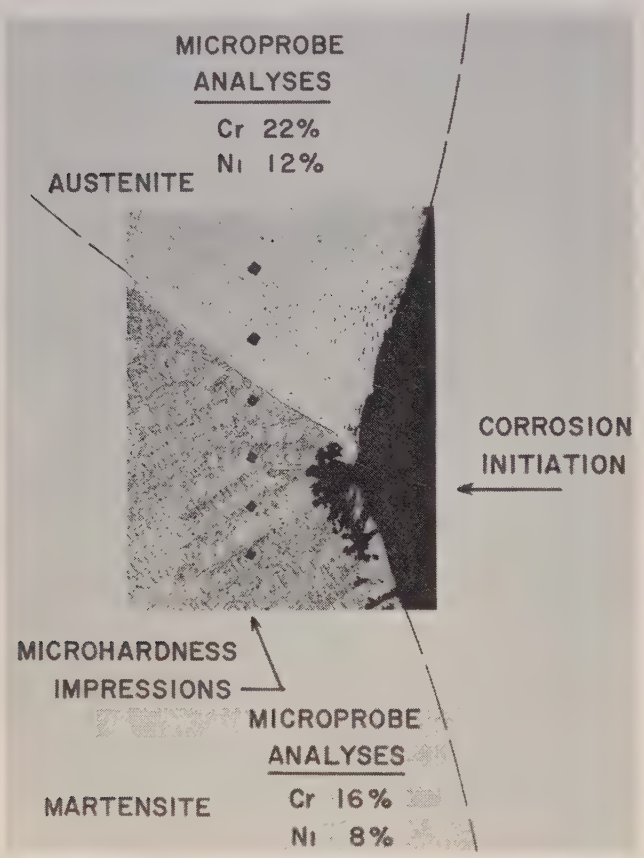

Fig. 8. Initiation of corrosive attack along fusion line of overlapping weld bead. Heterogeneous microstructure (martensitic) within adjacent weld deposit. Microhardness determinations verify transformation. Microprobe analyses show differences in alloy content

bead, analyzed by the microprobe to contain 16% Cr and 8% Ni, has been overlapped by the subsequently deposited bead. The latter bead has been formed under more favorable welding conditions and contains 22% Cr and 12% Ni. The lower-alloy bead is more readily etched by the metallographic reagent, and its structure has partly transformed to martensite. A traverse of microhardness determinations across the two beads indicates a hardness of Rockwell 21-C (by conversion) in the upper, high-alloy bead and Rockwell 36 to 40-C in the lower, lean-alloy bead. The limited attack shown at the extreme edge of the lean-alloy bead occurred over a 2-year period. This evidence suggests that either a 16 Cr- 8 Ni composition is close to being adequate for kraft pulping service, or the particular vessel is being operated under conditions which are comparatively mild from a corrosion standpoint.

Further confirmation of the deleterious effect of localized areas low in alloy content, and the secondary role played by hot cracks or microfissures can be found in Fig. 9 and 10. This overlay can be plainly seen to have many areas of dark-etching and martensitic structure distributed at random throughout each bead. Deeply penetrating furrow attack has progressed more than three-quarters through the third bead from the bottom of the illustration. The bottom bead contains an internal hot crack. Localized corrosive attack is taking place on the surface of the bottom bead just

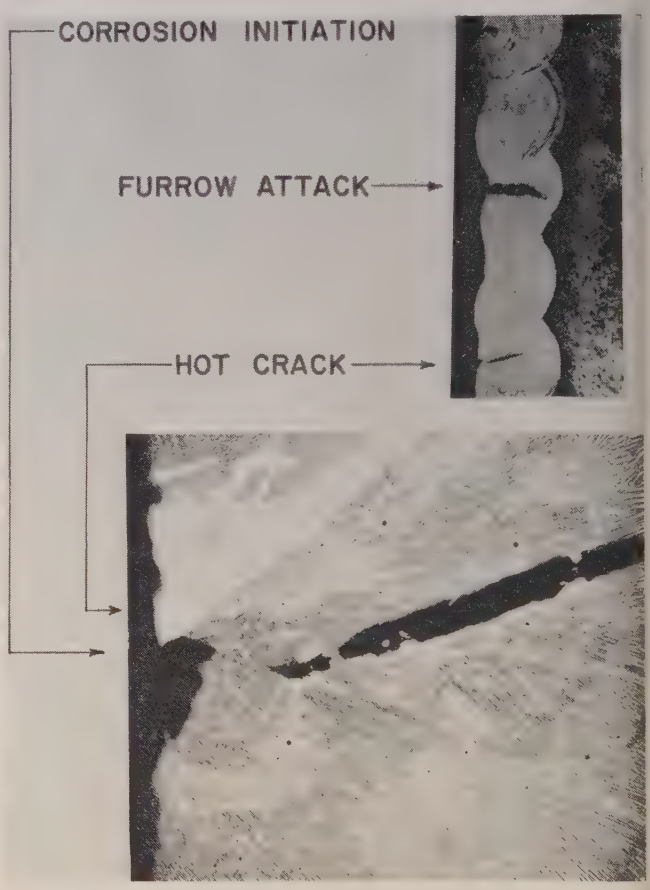

Fig. 9. Additional evidence of detrimental effects of heterogeneous weld microstructure. Corrosive attack has initiated within the martensitic structure of the adjacent weld bead. A weld metal hot crack extends into the center of the bead and provides easy access to the interior of the overlay deposit

above the hot crack because of the presence of lean-alloy weld metal. The lack of alloy is indicated here by the rapid-etching of the structure and the difference in hardness as shown by the microhardness impressions in Fig. 10. Some galvanic action probably is assisting the attack because of the higher-alloy, austenitic area of weld metal along the lower edge of the second bead immediately above. If the localized attack were to continue through to the hot crack, no doubt a deep furrow would develop like that observed in the third weld bead in Fig. 9.

Hot Cracks or Microfissures

At this point, hot cracks have been shown to play a secondary role in the corrosive attack on overlay linings, that is, by merely providing ingress for the pulp liquor to lean-alloy areas in the interior of the beads. Naturally, this brings up a question as to the deleterious effect of hot cracks *per se*. Some evidence has been found that hot cracks will not necessarily encourage accelerated corrosion of the overlay if the composition and structure are more like that of a normal, austenitic stainless steel weld overlay. Figure 11 illustrates an overlay containing a large hot crack which extends to the surface. This particular lining was recognized to

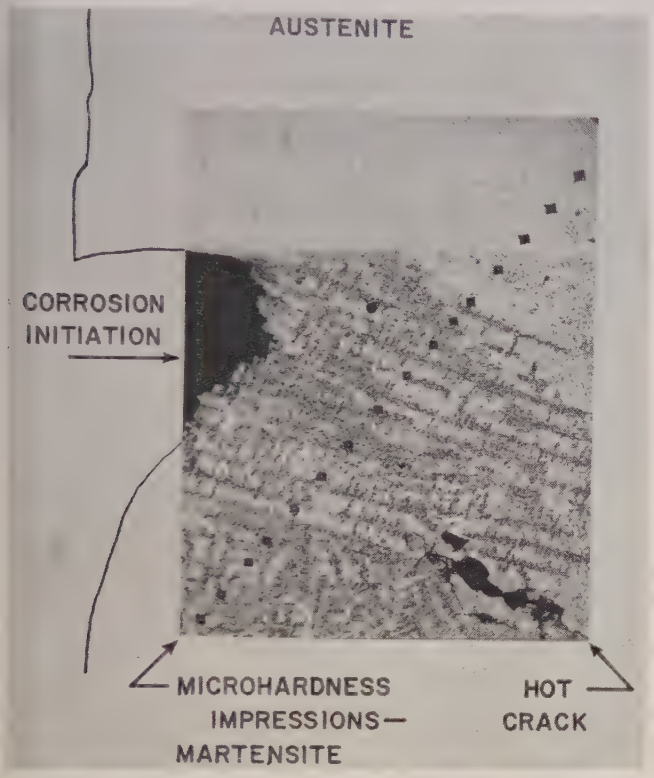

Fig. 10. Magnified portion of Fig. 9. Hot crack within 0.012 in. of the deepest local corrosion penetration. Surrounding microstructure is martensite, as indicated by etching reactions and microhardness measurements

contain many similar hot cracks which were readily seen on the surface, yet the lining is reported to be virtually unchanged in appearance after more than 2 years of service. Under metallographic examination, the weld beads making up the overlay are observed to have a uniform, wholly austenitic structure. No localized corrosive attack of significance has occurred either on the original surface of the lining or along the faces of the hot crack. The average chemical analysis of this particular overlay was determined as 15% Cr and 12% Ni.

Other Forms of Corrosive Attack

A number of small, fine fissures can be seen in Fig. 11 in close proximity to the main hot crack. This is believed to represent traces of stress-corrosion cracking. No sign of this form of failure has been found along the original surface of any overlay. Therefore, this defect apparently occurs only after a hot crack or furrow has provided a crevice that serves to concentrate the necessary corrodents and stress.

Intergranular corrosion was sought in the specimens, since this form of attack was reported to be suspected of causing overlay damage. Only one very mild case of intergranular corrosion was observed among the specimens examined despite the presence of precipitated intergranular carbides (sensitization) in the microstructure of most of the specimens. For this reason, intergranular attack is not considered a significant factor in the corrosion of stainless steel weld overlay.

DISCUSSION OF FINDINGS

From the evidence obtained in this laboratory investigation, the principal accelerated corrosion found on

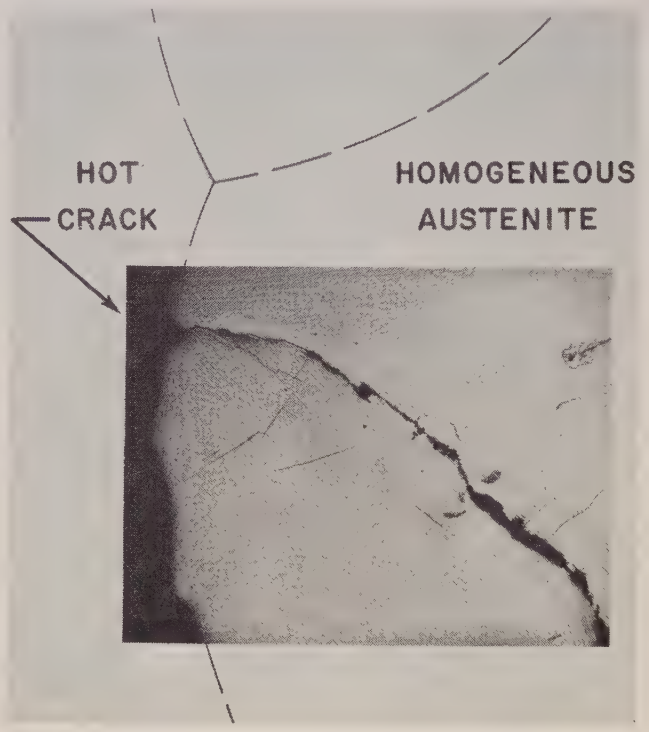

Fig. 11. Cross section of weld overlay containing hot crack in a homogeneous austenitic microstructure. No appreciable enlargement of hot crack width is reported after 2 years service even though the crack is open at the surface

weld overlay from pulp service appears to be attributable to a single basic cause—low alloy content. However, the deficiency of alloy is not a simple, overall or general condition. Instead, the problem can be described as sporadic heterogeneity in the overlay. This condition apparently has been introduced by unfavorable welding technique which deposited metal that did not undergo the usual, complete mixing of weld and base metals. Small irregular-shaped masses of molten carbon steel did not completely alloy with the stainless steel deposited by the electrode and consequently remained in the weld beads as small islands of lower-alloy content metal.

Excessive weld travel speed is believed to be chiefly responsible for the low-alloy heterogeneity in the weld overlay. This is suggested by the pattern of lean-alloy areas throughout the weld beads. This suspicion has

been confirmed to a degree by information from fabricators who reported using the automatic arc-processes at travel speeds upward of 75 in. per min. Most experience with dissimilar weld overlay in other applications involves weld travel speeds that generally are well below 50 in. per min. Little information is available on the length of time the weld pool must remain molten (and undergo electromagnetic stirring under the arc) in order to solidify as a homogeneous weld bead. However, the period over which the weld remains molten is determined mainly by the weld travel speed. Other factors like weld bead size and welding current are of secondary importance.

Although the serious attack on the overlay linings has varied in its appearance, ranging from deep furrows or grooves to more general attack on whole weld beads, the presence of localized areas of low alloy content has been the basic cause of attack in every case examined. The occurrence of hot cracking in the beads during welding apparently is a secondary factor that can markedly affect the mode and rate of attack. Hot cracks provide an inroad for the pulp liquor to easily reach a greater number of alloy-lean areas, and also permit concentration of liquor within the cracks when the pulp batch is discharged. Hot cracks cannot be singled out as a direct cause of corrosion because weld overlay with a uniform, high-alloy austenitic structure has not displayed accelerated attack despite the presence of hot cracking which extended to the surface.

RECOMMENDATIONS TO IMPROVE OVERLAY LININGS

In view of the forms of corrosion attack and their causes as determined by the laboratory study, the following can be cited as desirable features of an overlay lining regardless of the welding process employed:

1. The deposited beads must form a continuous layer free from skips, deep crevices, or failure to overlap properly.

2. The chemical composition of the overlay must be as uniform as can be expected from properly regulated arc welding. Certainly, no marked evidence of heterogeneity should appear in the weld microstructure.

3. A high-alloy content should be attained in the overlay, either by minimizing dilution or by making alloy additions through a flux or supplementary filler wire. The chromium content, particularly, should be maintained at a high level since this element is chiefly responsible for the corrosion resistance of stainless steel.

4. Hot cracking or microfissuring should be minimized. The conditions which promote the appearance of this kind of cracking in stainless steel weld metal are reasonably well understood, and one or more of the established remedies can be effectively applied. Briefly, most of the changes which probably will be considered for reasons of corrosion resistance also hold promise of helping to eliminate hot cracking.

Welding Technique

The exact welding conditions that will insure the above features in a single-layer overlay cannot be spelled out in detail. The permissible conditions will vary with the welding process employed, the cleanliness and smoothness of the base metal surfaces, the welding materials applied, and other variables. However, it appears especially important that weld travel speed be slow enough for the prevailing conditions to insure proper stirring or mixing of the weld pool and thus guard against marked heterogeneity of composition and structure in individual weld beads. Naturally, welding conditions must be controlled in a manner to obtain reasonable uniformity from bead-to-bead. Experience in other fields which demand a high degree of weld quality and reliability should be very helpful in setting up controls for digester overlay linings. It appears that a practicable system of control should be based upon requirements for the structural uniformity, chemical composition, and thickness of the actual overlay rather than qualification and approval of a specific welding procedure.

General Weld Composition

The general chemical composition of the actual weld overlay is bound to receive much consideration in the future, particularly if requirments are setup for the minimum levels of alloy elements.

Very little data are available that would shed light on the minimum amounts of chromium and nickel required to give adequate corrosion resistance to weld metal for kraft pulping service. The analytical data gathered in the present investigation suggest that the lowest desirable chromium content is somewhere in the range of 15 to 18%. Perhaps to insure sufficient corrosion resistance for even the most demanding kraft service, the overlay should contain a minimum of 18% chromium. While the nickel content assists in gaining a high level of corrosion resistance, its principal function is to maintain a soft, tough austentic microstructure in the overlay. A minimum nickel content of 10% should be more than adequate for these purposes, and would be easily obtained in the overlay with the regular ER-310 welding wire. On the other hand, there may be some virtue to nickel contents in the range of 8 to 10% with respect to hot cracking. This lower level of nickel would allow a small amount of delta or free ferrite to be retained in the weld microstructure. Delta ferrite has been established as a very effective suppressor of hot cracking susceptibility (*1*). This weld composition and structure would require departure from the E-310 weld wire, and depending on the process employed, may be obtained with an E-309 (25-12) composition.

Use of Molybdenum

Molybdenum has been used to some extent in the composition of weld overlay in efforts to avoid accelerated corrosion and to avoid hot cracking. The advocates of the molybdenum addition have pointed to the improved pitting corrosion resistance offered by the Type 316 and Type 317 stainless steel compositions to justify its inclusion in weld overlay. They also believe that molybdenum reduces hot cracking tendency in the weld metal through the strengthening effect of this element at elevated temperatures. Molybdenum in the order of 1 to 2% has been secured in the overlay by use of E-316, E-317, and special 310-Mo welding wire. To the authors' knowledge, there is no sound basis for expecting molybdenum to effectively suppress hot cracking susceptibility in a high-alloy weld deposit which solidifies with a wholly austenitic structure. Some laboratory work, for example by Hull (*2*), has been carried

out on cast specimens which suggests this benefit from molybdenum. However, there is evidence from tests and experience with actual welding (*3*, *4*), that molybdenum does not provide any real relief from this defect, unless, by course, the molybdenum is increased to a level where its ferrite-forming influence causes the appearance of delta phase in the solidifying weld metal. A more direct piece of information concerning the inability of molybdenum to prevent hot cracking in overlay was obtained in the present study. Samples of overlay linings made in the field with two different Cr-Ni-Mo welding wire compositions displayed hot cracking in four out of five cases. The degree of cracking was small and four was considered equal to that frequently observed in overlay from E-310 weld wire deposited under similar circumstances.

A more important aspect to consider in using molybdenum in the overlay composition is whether the corrosion resistance will be improved by this element, or whether the weld overlay will be subject to accelerated corrosive attack as is sometimes experienced with as-deposited Cr-Ni-Mo weld metal (*5*, *6*, *7*). The behavior of Cr-Ni-Mo weld metal in the as-welded condition varies widely in different corrosive media, and no positive way of predicting its performance has been devised. While arrangements have been made to sample and observe the action of pulp service conditions on molybdenum-containing overlay, it will be some time before sufficient data are collected to attempt an evaluation of any benefit from molybdenum. Meanwhile, careful consideration should be given to the known "side-effects" of this element in stainless steel weld metal.

Control of Hot Cracking

Hot cracking was the only form of unsoundness found in the overlay samples; and, as described earlier, hot cracking appears to play a secondary role in the corrosive attack observed. This defect was more often present as internal microfissures which did not extend to either the top surface or to the weld-base interface. Yet, it appears prudent to strive for elimination of this defect to avoid any possible effects upon corrosion resistance should the pulp liquor enter these crevices. The action taken to avoid hot cracking or microfissuring will depend upon the character of the microstructure in the weld overlay.

With wholly austenitic weld metal, as is presently being deposited, the following precautions in welding will act to prevent hot cracking:

1. Apply weld beads no larger than that required to adequately meet thickness requirements.
2. Deposit the narrowest beads practicable for the particular conditions of process and lining thickness.
3. Employ slower weld travel speeds. Hot cracking susceptibility increases markedly as speed increases.
4. Maintain silicon, sulfur and phosphorus contents of weld metal at lowest possible level by (a) avoiding welding on vessel surfaces that are contaminated with sulfur-bearing compounds, and (b) minimizing dilution with the carbon steel base metal which is not necessarily very low in sulfur and phosphorus contents.

A ferrite-containing austenitic weld structure would offer more positive control over hot cracking. Incidentally, it would be the authors' recommendation to employ this two-phase structure only with a nonmolybdenum (plain Cr-Ni) overlay composition until assurance had been gained that pulp liquors will not preferentially attack the delta phase in a Cr-Ni-Mo weld structure. Delta or free ferrite can be secured in a regular Cr-Ni austenitic weld structure by raising the chromium content and decreasing the nickel until the Cr-Ni ratio is about 1.80 or higher. Accordingly, weld overlay containing 18% chromium should have no more than 10% nickel present. Yet, the nickel must be above about 8% to maintain a soft, tough austenitic structure. The various welding processes present different problems in obtaining a ferrite-containing austenitic structure in the overlay because of the conditions surrounding available weld wire grades, dilution to be expected, loss of alloy through oxidation, and methods of making alloy additions.

Consideration of a Double-Layer Overlay Lining

Mention is made here of double-layer overlay linings because a number of engineers have commented that such linings have shown outstanding corrosion resistance in pulp service. Areas of double-layer overlay have been created unintentionally where repairs have been made to corroded single-layer linings or where the surfaces of the corroded carbon steel vessel have been built-up in localized areas to secure uniformity for a complete overlay to be deposited by an automatic welding process.

In planning the installation of a double-layer lining, each layer can be deposited with a particular grade weld wire which is best suited for the conditions encountered. The first electrode wire can be one which deposits a layer having sufficient alloy to maintain a tough, austenitic structure, yet balanced in composition to retain some delta or free ferrite to prevent hot cracking. The second layer can be made with a lower-alloy electrode wire, and microstructure can be regulated as desired. The second layer will not be subject to drastic composition changes by dilution directly with the carbon steel, and therefore would be expected to possess a uniform, high-alloy microstructure free of hot cracking.

Experience in overlay welding the inside surface of vessels for the chemical industry and nuclear power service has shown that a double-layer lining more easily achieves the desirable conditions of high alloy content, homogeneity, and soundness. While the critical nature of the nuclear usage more than justifies the cost of a double-layer, the pulp digester application might make use of the two-layer technique if there were no great increase in cost.

CONCLUSIONS

All of the evidence obtained from specimens taken from pulp digesters in service indicated composition heterogeneity and low level of alloy content to be the causes of the principal forms of corrosive attack on stainless steel weld overlay linings. These conditions appear related to the welding technique employed and probably can be corrected through development of suitable procedures for any of the arc-welding processes. It would appear helpful in future lining installation to sample the overlay and examine for uniformity, composition, and thickness.

CURRENT RESEARCH ON WELD OVERLAY

A number of projects are underway in the authors' laboratories in an effort to obtain information that will be helpful in producing stainless steel weld overlay linings that give trouble-free service. Briefly, these activities may be divided into studies of (1) welding conditions and (2) development of improved welding wire for use with the various applicable processes.

Study of Welding Conditions

Experiments are being conducted with the various welding processes to obtain information on the influence of factors like travel speed, welding current, and polarity with respect to weld metal composition uniformity. The objective is not to establish definite welding procedures for overlay, but to determine the principal conditions which must be controlled to insure composition and structural uniformity and high alloy content. Specimens are now being prepared in the laboratories and in the field by lining fabricators. While this work is far from being complete, the experiments are producing results of considerable interest.

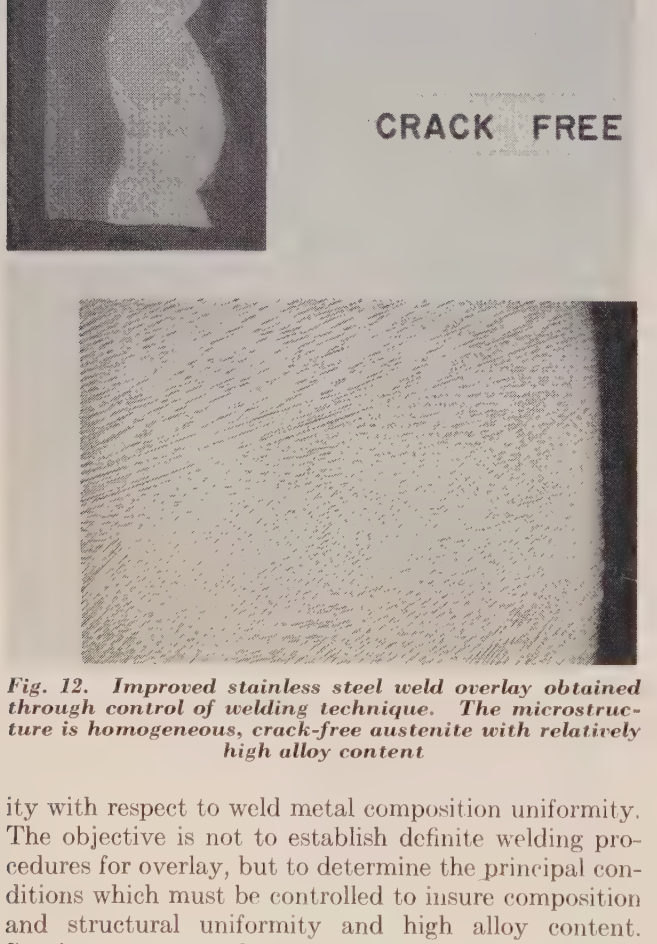

Fig. 12. Improved stainless steel weld overlay obtained through control of welding technique. The microstructure is homogeneous, crack-free austenite with relatively high alloy content

Welding speed already appears to be an important variable in single-layer linings, and the following general remarks can be made about the outcome of tests to date:

1. Slow welding speed decreases the likelihood of any marked heterogeneity in the overlay structure (see Fig. 12).
2. With constant welding current, slower weld speed results in a higher average level of total alloy content in the weld bead.
3. Hot cracks and microfissures are prone to occur in beads deposited at high travel speed, but may be absent in beads deposited at low speed.

Development of Improved Welding Wire

In general, the standard type of stainless steel welding wire was not developed with dissimilar metal overlay welding in mind. Past experience has shown that in dissimilar metal welding, improvements in the quality and performance of stainless steel weld deposits can be made most effectively through small changes in weld metal composition.

The importance of the weld overlay lining activity warrants consideration of a weld wire alloy tailored for this application. The first step in a methodical study will be to establish the alloy composition and microstructure of overlay which gives adequate corrosion resistance and mechanical properties for pulp service. Refinements then can be made in this composition to secure optimum characteristics in welding. For example, a substantial addition of manganese possibly will be useful in gaining resistance to hot cracking or microfissuring (*8*). However, the development of a new, improved welding wire is an activity which must, by necessity, proceed slowly, since great care must be exercised that modifications made to enhance welding properties will not endanger the longtime service performance of the overlay lining.

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The Energy of Tensile and Cleavage Fracture of Black Spruce

D. ATACK, W. D. MAY, E. L. MORRIS, and R. N. SPROULE

It has been shown that the principle of energy balance, originally proposed by Griffith for brittle fracture and extended by Orowan to include certain types of ductile fracture, provides a satisfactory criterion for the onset and propagation of tensile and cleavage fracture of green spruce along the grain within a range of strain rates prior to fracture of 2×10^{-4}–2×10^{-3} sec.$^{-1}$. Under the test conditions described, green spruce fractures in a ductile fashion. Experimental values of the effective surface energy, P, (the energy required to create a projected unit area of surface) have been obtained and are of the order of 1×10^5 ergs/cm.^{2} The effective surface energy is the sum of two terms: $P = \gamma + p$, where γ is the surface free energy and p is the plastic work. Since γ is of the order of 500 ergs/cm.^{2} plastic work is dissipated during the fracture. Scanning electronmicrographs of fracture surfaces are given and their significance is discussed. Amongst other things the micrographs show that fracture surfaces are quite rough for specimens fractured at room temperature and relatively smooth for specimens fractured close to 100°C. The corrected surface energy is thus lower at the lower temperature. Since the fracture surfaces are not plane, it is not possible to derive an absolute value for the surface energy involved in these types of fracture until an accurate measurement of the surface area development has been made. However there is little doubt that the surface energy required for fracture greatly exceeds the probable value of the surface free energy of wood. A note of caution is introduced regarding the possible use of such data in estimating a theoretical efficiency of mechanical pulping processes.

NOMENCLATURE

b	=	width of specimen, cm.
c	=	crack length, cm.
E	=	Young's modulus, kg./cm^2.
F	=	normal force, kg.
I	=	moment of inertia of rectangular beam about its neutral axis, cm.^{4}
$M(x)$	=	bending moment of beam at point x along a beam, kg.-cm.
n	=	thickness of specimen, cm.
p	=	plastic work per sq. cm. of projected area, ergs/cm.^{2}
P	=	effective surface energy per sq. cm. of projected area, ergs/cm.^{2}
p_c	=	plastic work per sq. cm. of true area, ergs/cm.^{2}
P_c	=	effective surface energy per sq. cm. of true area, ergs/cm.^{2}
U	=	strain energy, ergs
V	=	total energy required for formation of new surface, ergs
γ	=	surface free energy, ergs/cm.^{2}
δ	=	displacement of open end of cleavage crack, cm.
σ	=	tensile strength, kg./cm.^{2}

STUDIES of fracture have assumed an increasing significance in this age of high-speed machines and highly strained mechanisms, and considerable progress has been made toward defining some of the basic causes of fracture (*1*). In particular, a theory of brittle fracture has been reasonably well established, and has recently been shown to apply, with some slight modification, to certain types of ductile fracture. This paper describes an investigation, based upon this modified theory, of the criteria which govern the onset, propagation, and energetics of certain simple types of ductile fracture of moist wood. It is anticipated that these studies may be extended to more complex types of fracture and will thus eventually lead to a better understanding of mechanical pulping processes (*2*).

Brittle fracture is generally thought to be initiated by the action of stresses upon a host of minute flaws or inhomogeneities which occur in every solid. When external forces are applied to a solid body, stress concentrations are produced at these flaws causing them to grow and form larger cracks. Propagation of one or more of these cracks then leads to rupture. Crack propagation and the accompanying formation of new surface in a strained solid body requires energy, and this energy is supplied from the elastically stored potential energy, or strain energy, in the body. It was suggested by Griffith (*3*), that the increase in the potential energy of a body due to the surface tension of a crack propagating in it must be balanced by a simultaneous decrease both in the strain energy stored in the body, and in the applied forces. An obvious corollary of this suggestion would be that the solid body must contain an amount of stored elastic energy at least equivalent to that required to form the new surface.

Griffith successfully developed this criterion of fracture theoretically, and verified it experimentally for the brittle fracture of glass. Numerous subsequent tests of the criterion by other workers, for a wide variety of brittle materials, have confirmed in each case that it provides a satisfactory first approximation to the observed behavior (*4*).

Employing the energy-balance criterion of fracture, Griffith derived an expression for the tensile strength of a solid containing a single elliptically shaped crack passing right through the solid, when a tensile force is applied in a direction perpendicular to the direction of the crack. This expression takes the following form:

$$\sigma = \left(\frac{4E\gamma}{\pi c}\right)^{1/2} \qquad (1)$$

This relation presupposes that the material is elastic, homogeneous, isotropic, that it has a linear stress–strain curve to fracture, and that the crack propagates to produce a plane fracture surface. The equation affords a means of testing the validity of Griffith's criterion for brittle fracture, if it is physically possible to create cracks of different lengths in separate specimens of the material. The tensile strength should then be inversely

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proportional to $c^{1/2}$ if the criterion applies. If the form of the equation is verified in this way for a material, then the energy associated with the creation of surface in it may be calculated. For such materials as glass, mica, and several crystalline materials in which little or no viscous energy is dissipated during fracture, the value of the surface free energy obtained in this manner compares quite well with values obtained by other methods (*5*). These values generally lie in the range 100 to 1000 ergs per sq. cm.

A rather interesting feature of the Griffith equation is that although it provides a necessary and sufficient condition for brittle fracture, a modified form of it can be applied to a certain type of ductile fracture. In this respect it should be noted that brittle fracture may be defined as one which occurs without dissipation of energy due to plastic deformation, and is generally a low-energy fracture; whereas ductile fracture is one which is accompanied by plastic deformation and is generally a high-energy fracture. Certain materials have been shown to fracture in either brittle or ductile fashion, depending upon the temperature at which fracture occurs. Thus, brittle fracture occurs in several metals and polymers below a certain temperature, characteristic of the material, and ductile fracture occurs above this temperature. For metals this temperature is generally known as the embrittlement temperature. There is also evidence to suggest that the brittle–ductile transition is affected by the rate of strain preceding fracture.

Orowan (*6*) has proposed that the Griffith principle may be employed only for those types of ductile fracture where the plastic deformation is confined to a thin layer at the crack walls while the bulk of the specimen remains in a state of elastic strain. Under these conditions the concept of energy balance may be retained, but in addition to the surface free energy being provided by the release of elastic-strain energy from the stress field, the elastic-strain energy may also be dissipated in plastic deformation. In all other types of ductile fracture, where gross plastic deformation occurs (often giving rise to "necking" of the specimen) the Griffith principle is not applicable.

For the type of ductile fracture which conforms to the principle of energy balance described, an expression of the Griffith type may be employed in which the surface free energy term, γ, is replaced by a term, P, representing the effective surface energy. The equation for ductile fracture than becomes:

$$\sigma = \left(\frac{4EP}{\pi c}\right)^{1/2} \qquad (2)$$

The effective surface energy, P, represents the total energy required to create unit area of surface in this type of fracture, assuming the fracture surface to be plane. It may be written as the sum of two terms:

$$P = \gamma + p \qquad (3)$$

where γ is the true surface free energy and p is the plastic work dissipated in the creation of unit surface area. The surface free energy is a physical constant of the material and shows a slight variation with temperature, but is independent of all other conditions which may lead to surface production. The plastic work p, however, is a quantity whose value will depend markedly on both the temperature and the conditions leading to the creation of new surface. It will be noted that if the fracture surface is not plane an area correction must be made. The corrected value of the surface energy, P_c, will then be less than P, and hence the corrected value for the plastic work, p_c, will be less than p.

Values of the effective surface energy obtained for fracture of ductile materials are often of the order of 10^5 to 10^6 ergs per sq. cm. and may even be as high as 10^8 ergs per sq. cm. These values are very much higher than the true surface free energy of these materials. It is thought that plastic flow precedes the formation of cracks of a certain critical size, which can then propagate by the Griffith type of energy transfer mechanism. This fracture mechanism is generally such that, except at very high speeds of propagation, plastic flow also occurs ahead of the crack tip.

A variety of experimental methods have been employed for the determination of the effective surface energy. Probably the most straightforward, and the one most frequently used, is the direct measurement of the work required to create new surface, using some kind of straining machine, coupled with a measurement of the surface area created. In some cases the plastic work alone has been measured (*6*).

TEST OF THE VALIDITY OF THE MODIFIED GRIFFITH EQUATION FOR THE TENSILE FRACTURE OF WOOD PARALLEL TO THE GRAIN

Sample Preparation

A large number of samples of straight-grained eastern black spruce (*Picea mariana*) were prepared having dimensions 4 by 1.5 by 0.25 in. in the radial, tangential, and longitudinal directions, respectively. A typical sample is shown in Fig. 1. All samples were cut from a selected freshly cut 4-ft. log, and pieces containing knots were rejected. The samples were gently abraded against 600-grit emery paper under water to smooth the surfaces, and remove any large surface discontinuities.

A centrally located crack of predetermined length was incised in the tangential–longitudinal plane of each sample, using a scalpel. Incisions were made from both sides of the wood and each crack extended completely through the wood in the longitudinal direction. The crack lengths in the different samples were varied through the range 0.4 to 1.6 cm. in the tangential direction.

Fracture in the Longitudinal–Tangential Plane

Each sample was strained at room temperature (23°C.), on an Instron tensile testing machine using a crosshead speed of 0.1 cm. per min., which corresponds to a rate of strain of 2×10^{-4} sec.$^{-1}$. The strain was applied normally to the crack direction. When the wood commenced to fracture the tensile force on the Instron recorder decreased almost instantaneously and the maximum value of the tensile force, F, was noted. A typical tensile force–displacement curve for the straining sequence to fracture is shown in Fig. 2, which is a reversed tracing of an Instron recording. The dotted line is a tangent to the curve at the point of fracture. It will be noted that the force–displacement curve is almost linear up to the point of fracture.

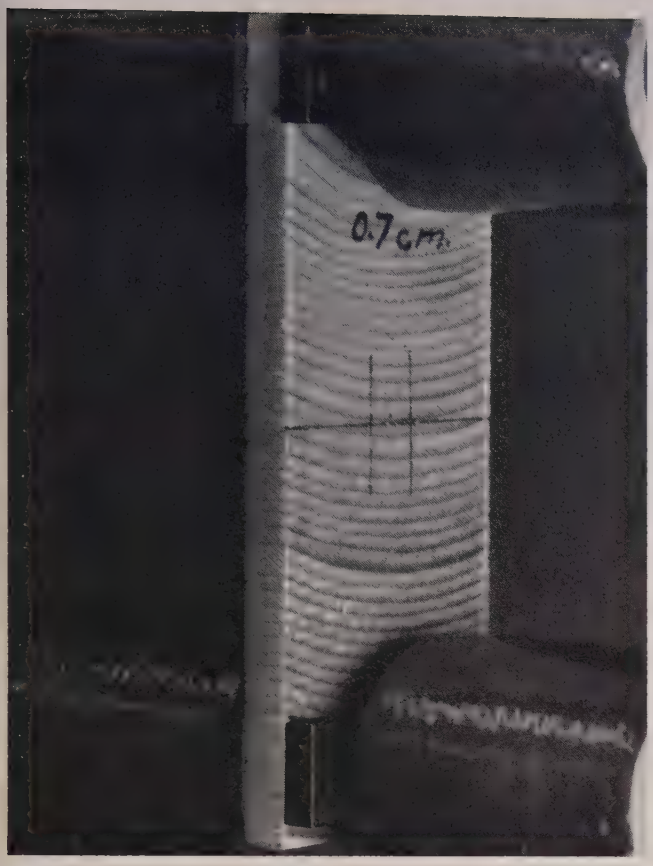


Fig. 1. Specimen prepared for tensile fracture in the longitudinal–tangential plane, shown held in the jaws of the tensile tester prior to straining

Fracture was initiated from a centrally located crack incised in the specimen. The position and length of the crack are marked on the specimen.

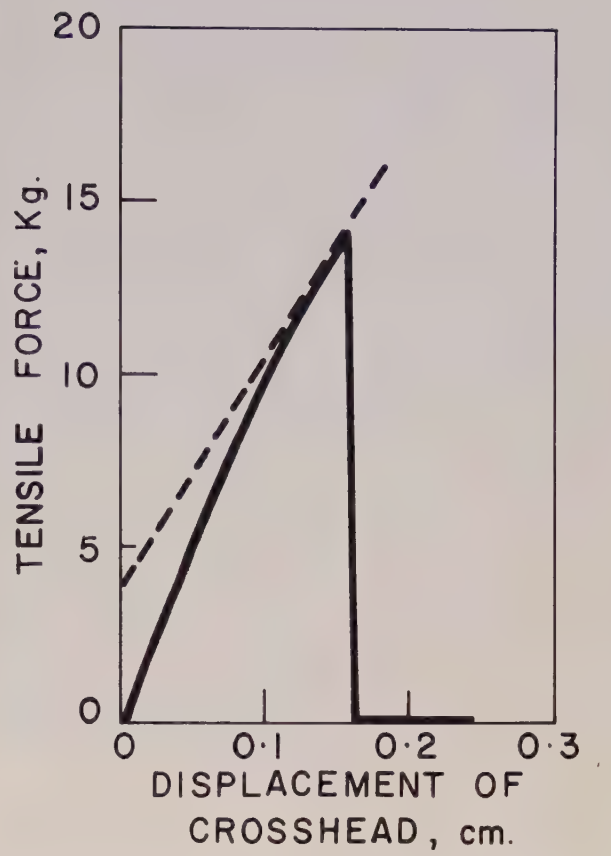


Fig. 2. Typical force–displacement curve for tensile straining to fracture of green spruce specimen containing a centrally located crack

The behavior is almost linear at rates of strain prior to fracture through the range 2×10^{-4} to 2×10^{-3} sec.$^{-1}$. Both the ultimate tensile stress and Young's modulus at fracture are sharply defined.

The value of the tensile fracture force is sharply defined and the shape of the curve allows the Young's modulus of each specimen at fracture to be readily calculated from the tangent to the tensile force–displacement curve. It is important to measure the modulus for each sample, since wood is a biological material with grossly anisotropic structure, and consequently its Young's modulus is subject to considerable variation. Allowance must be made for this variation in testing the validity of the Griffith criterion.

There are two reasons for the variation of the Young's modulus of wood:

1. The growth of wood is influenced by environmental conditions and hence considerable variations in both rate and symmetry of growth are found to exist between trees. These variations are manifested in the physical and mechanical properties of the wood, and it is normal to find large variations in the Young's modulus of wood from trees of the same species. In order to reduce the variation of Young's modulus due to this cause in these experiments, all samples were cut from the same log, which was selected for its straight grain and its evenly spaced, almost circular, annual rings.

2. Wood is anisotropic and there is a difference between the Young's moduli along the three major axes of symmetry. This means not only that the samples have to be prepared carefully with respect to these axes of symmetry but also that care be taken to ensure that fracture proceeds along a plane which coincides as closely as possible with the longitudinal–tangential plane of symmetry. In choosing the sample dimensions quoted above a compromise was made between the following two factors: (a) samples had to be sufficiently large to allow a meaningful measurement of the tensile fracture force to be made for a series of crack lengths; (b) samples had to be small enough to avoid changes in the grain direction and gross departure from normality between the tangential and radial planes.

Despite these precautions it was found that a twofold variation in values of the Young's modulus was obtained between different samples. Figure 3 shows a typical logarithmic plot of tensile stress, σ, as a function of crack length, c, where no allowance is made for the variation in Young's modulus. The slope of the fitted line corresponds to a variation of tensile stress with crack length following a relationship: $\sigma = Kc^{-0.6}$.

In Fig. 4 allowance has been made for the variation in Young's modulus by plotting σ vs. Ec^{-1} on logarithmic coordinates. This does not result in any reduction in the scatter, which must therefore be due to some factor other than the modulus variation. The slope of the best fitting line through the points in Fig. 4 is 0.5, indicating that a relationship of the form $\sigma = K_1 E^{1/2} c^{-1/2}$ holds for this type of fracture of wood. Since this relationship is identical with the modified Griffith equation proposed by Orowan it is inferred that the bulk of the plastic work occurs in close proximity to the fracture surface.

Figure 5 is a plot of σ vs. $E^{1/2}c^{-1/2}$, and from the slope

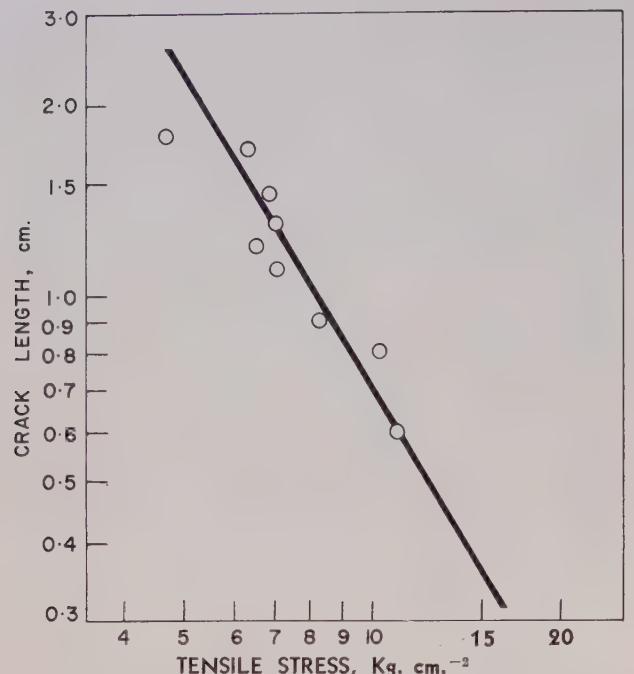


Fig. 3. Variation of tensile stress, σ, with crack length, c, on a logarithmic scale, for fracture in the longitudinal–tangential plane

The relationship is of the form $\sigma = Kc^{-m}$; $m = 0.6$.

of the line of best fit a value of 1.8×10^5 ergs per sq. cm. is obtained for the effective surface energy, P.

Fracture in the Radial–Longitudinal Plane

A similar series of experiments were carried out on samples from another log of eastern black spruce to investigate the fracture behavior along the radial–longitudinal plane. The log chosen had an average growth rate of 11 rings per inch, whereas the log used in the previous experiments had an average growth rate of 16 rings per inch.

Samples were prepared for fracture in the radial–

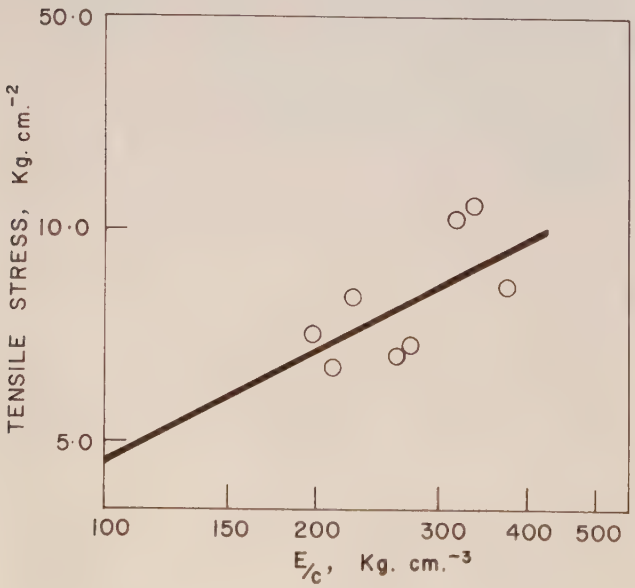


Fig. 4. Logarithmic plot of tensile stress, σ, as a function of E/c

The variation of Young's modulus between samples is allowed for in testing the Griffith relation. The relationship is of the form $\sigma = KE^n c^{-n}$; $n = 0.5$.

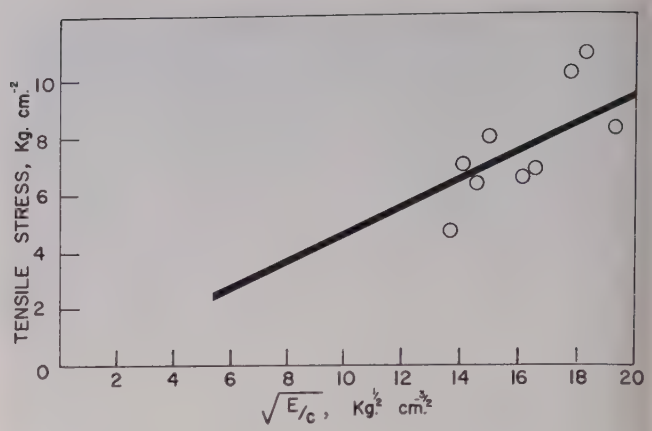


Fig. 5. Plot of tensile stress, σ, vs. (E/c)$^{1/2}$

The tensile stress is a linear function of $(E/c)^{1/2}$ for the fracture of green spruce at room temperature in the longitudinal–tangential plane.

longitudinal plane, having dimensions 4 by 1.5 by 0.25 in. in the tangential, radial, and longitudinal directions, respectively, and centrally located cracks were incised in the radial-longitudinal plane as shown in Fig. 6. At the same time, for comparison, samples were prepared for fracture in the longitudinal–tangential plane as previously described.

All conditions leading to fracture were as before. Figure 7 gives data for both radial and tangential fracture. It is seen that little difference exists between the fracture phenomena along the two different planes. The slope of the line of best fit corresponds to a value of the effective surface energy of about 1.0×10^5 ergs per sq. cm. This is about half of the value obtained previously, and it is possible that this difference may be a

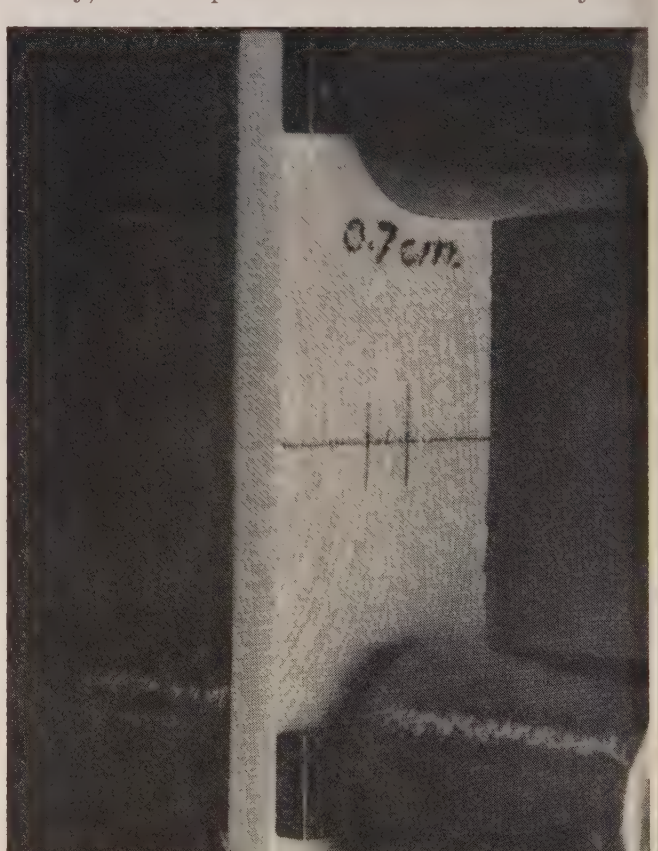


Fig. 6. Specimen prepared for tensile fracture initiated at a centrally located crack in the radial–longitudinal plane

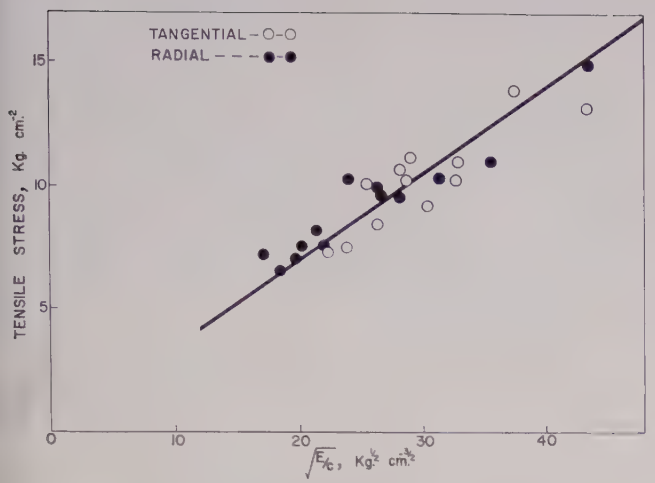


Fig. 7. The fracture behavior in the longitudinal–tangential and longitudinal–radial planes at room temperature, as shown in this type of plot, is substantially the same

function of the growth rate or density of the tree. The moisture content of the green wood in both cases was approximately 45%.

Effect of Temperature and Rate of Strain Prior to Fracture

It may be of interest to include preliminary, yet significant, experimental results on the effect of temperature and rate of strain prior to fracture.

(a) *Effect of Temperature.* Samples were prepared for fracture in the tangential–longitudinal plane, as shown in Fig. 1, and were immersed in boiling water for 3 hr. They were fractured immediately on removal from the water. The results are shown in Fig. 8. It will be seen that they are almost identical to those of Fig. 7, which were obtained at room temperature.

(b) *Effect of the Rate of Strain.* Similar samples were prepared and tested at room temperature in the Instron using a crosshead speed of 1.0 cm. per min. This corresponds to a rate of strain of 2×10^{-3} sec.$^{-1}$, and represents a tenfold increase in the straining rate. Typical data are shown in Fig. 9. A value of 0.7×10^5 ergs per sq. cm. is obtained from this curve for the effective surface energy. It was found that the Instron would not record the rate of development of tensile

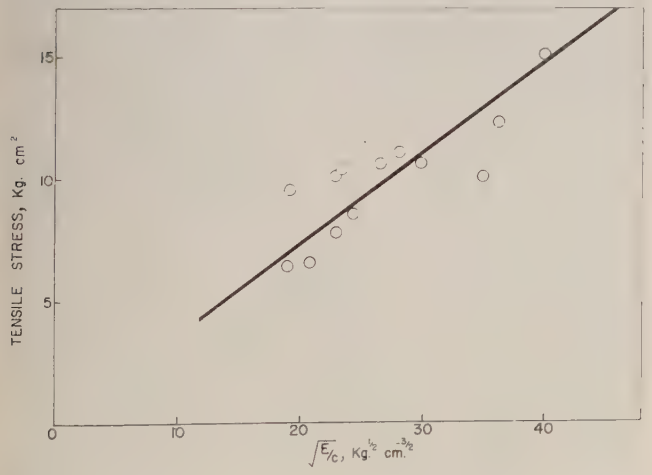


Fig. 8. Fracture behavior in the longitudinal–tangential plane at a temperature close to 100°C.

The plot is substantially the same as that derived for fracture at room temperature (Fig. 7). The force–displacement curves from which this plot is constructed are also very similar at the two temperatures.

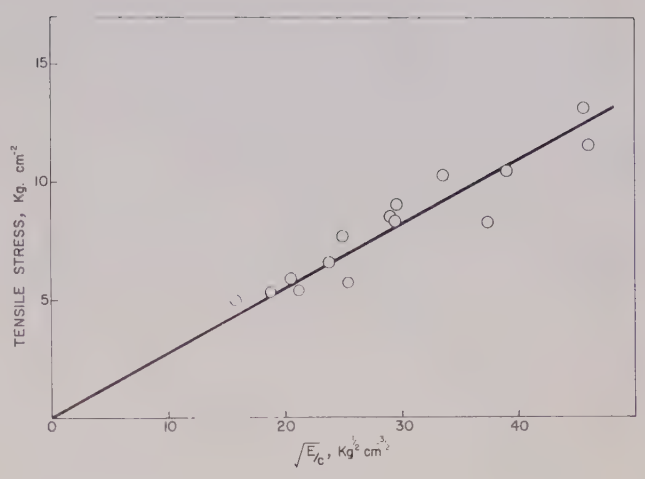


Fig. 9. Fracture behavior in the longitudinal–tangential plane at room temperature and at a rate of strain prior to fracture of 2×10^{-3} sec.$^{-1}$

force in the wood specimens for rates of strain greater than about 4×10^{-3} sec.$^{-1}$. It is interesting to speculate on the effect of further increases in the rate of strain, and experiments are being carried out on a different machine to investigate this.

CLEAVAGE FRACTURE OF WOOD ALONG THE GRAIN

Following the work of Obreimoff (*8*) on the cleavage of mica, and more recently that of Benbow and Roesler (*9*) on the cleavage of various polymers, it was decided

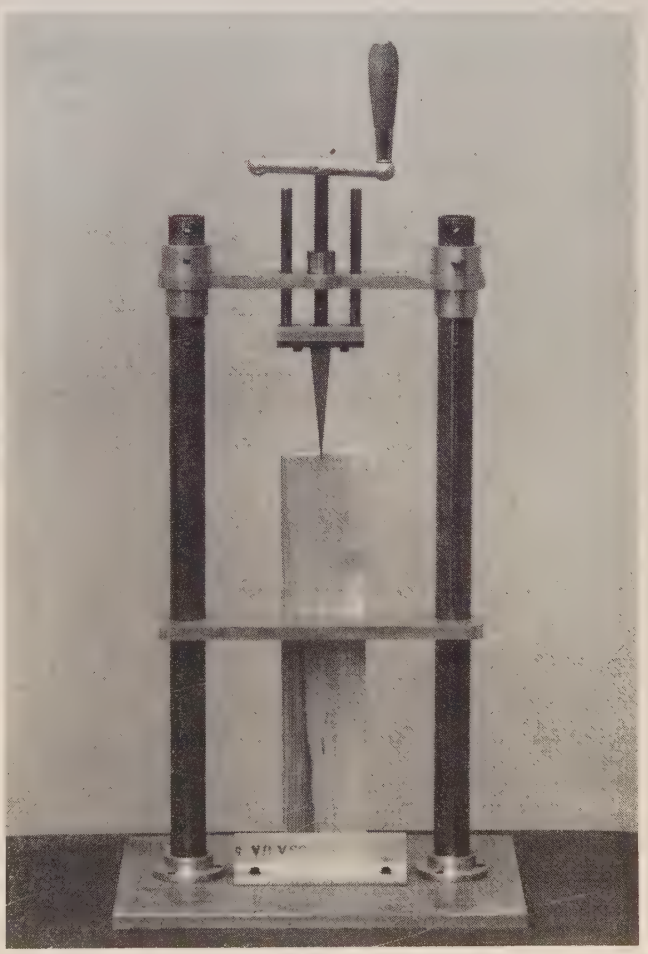


Fig. 10. Cleavage fracture apparatus

A thin steel wedge is slowly pushed along a central longitudinal–tangential plane of the wood.

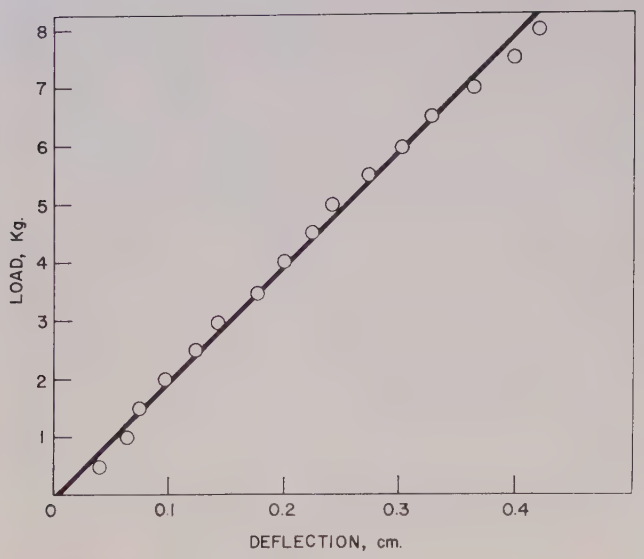


Fig. 11. Plot of load vs. deflection for specimen supported at two points 14 in. apart and loaded at the center

to investigate the cleavage fracture of wood parallel to its grain.

If a sample of wood is cleaved by a sharp wedge such as shown in Fig. 10, two new surfaces are created, and the energy required to produce the new surface can be calculated from the geometry of the strained wood along the cleavage crack. Although the theory of the mechanics of cleavage is reasonably well known, it may be worth recalling for these particular conditions.

Each of the two cantilever beams produced by the cleavage fracture contains an amount of strain energy, U, which is given by:

$$U = \frac{1}{2EI}\int_0^c [M(x)]^2 dx. \qquad (4)$$

In the present case $M(x) = F.x$, where F is the normal force exerted on the beam by the wedge. Thus:

$$U = \frac{F^2}{2EI}\int_0^c x^2 dx = \frac{F^2c^3}{6EI} \qquad (5)$$

If the maximum displacement between the crack edges (i.e., at the top of the specimen) is δ, then from Castigliano's theorem:

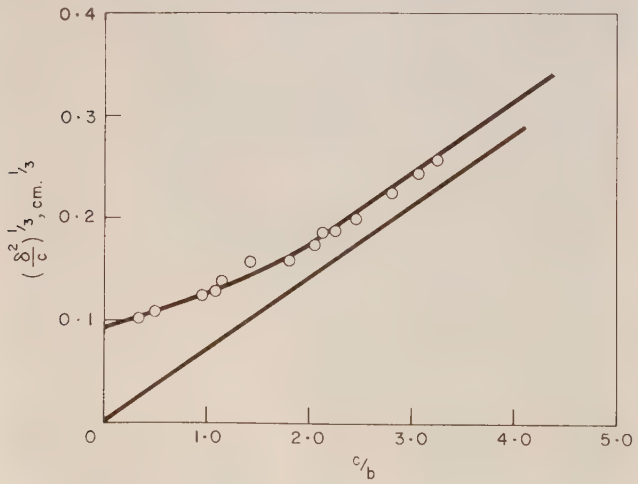


Fig. 12. Typical plot of $(\delta^2/c)^{1/3}$ vs. c/b

The value of the effective surface energy in cleavage fracture is obtained from this plot. The curve should be asymptotic to a line passing through the origin, and the effective surface energy is calculated from the slope of the asymptote. This plot is for a specimen having a total width of 3 in.

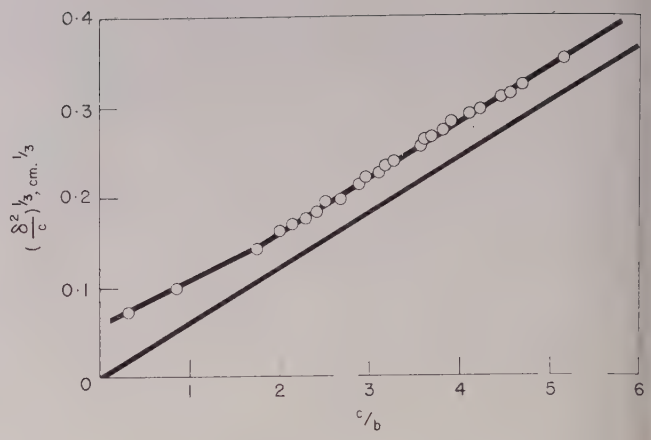


Fig. 13. A similar plot to that of Fig. 12, but for a specimen 1.5 in. wide

The similarity between the two plots provides justification for the energy balance mechanism of fracture in cleavage.

$$\frac{\delta}{2} = \frac{\partial U}{\partial F} = \frac{Fc^3}{3EI}$$

$$\therefore U = \frac{3}{8}\frac{EI\delta^2}{c^3} \qquad (6)$$

Writing the Griffith criterion in its fundamental form as an energy balance:

$$-\left(\frac{\partial U}{\partial c}\right)_\delta = \left(\frac{\partial V}{\partial c}\right)_\delta \qquad (7)$$

where V represents the total energy required for the formation of new surface in each piece after splitting, and:

$$V = Pnc \qquad (8)$$

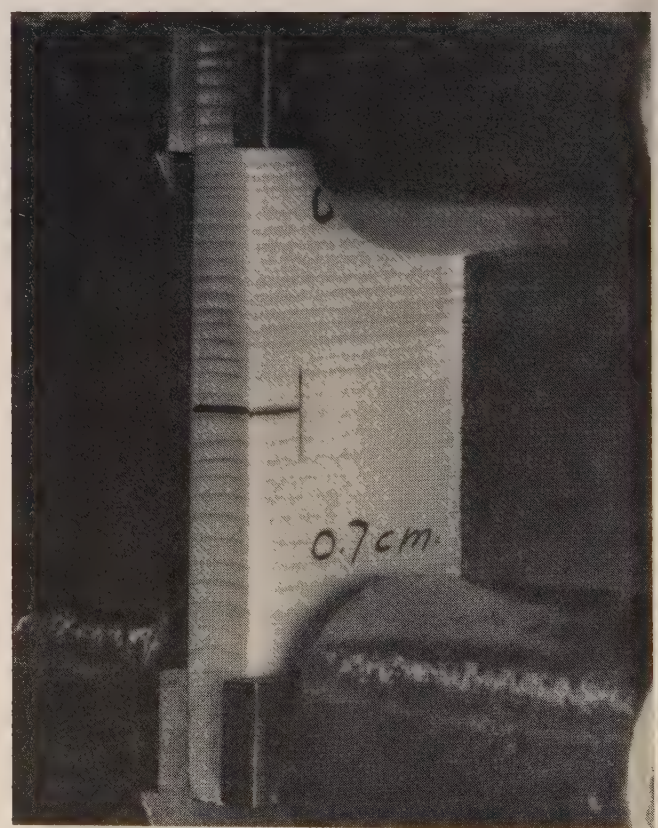


Fig. 14. Specimen prepared for tensile tearing from an edge crack in the longitudinal-tangential plane

The length and position of the crack are marked on the specimen.

Combining (6) and (7) we obtain

$$P = \frac{9}{8}\frac{EI}{n}\frac{\delta^2}{c^4} \qquad (9)$$

Thus, provided that the Griffith criterion holds, the energy required to create new surface during cleavage fracture may be obtained through the use of equation (9).

The experimental procedure for slow rates of fracture propagation is simple. Each time the wedge is advanced the crack elongates a certain amount, and both the new crack length, c, and the lateral displacement, δ, are measured when the crack reaches equilibrium.

Specimens having dimensions of approximately 15 by 3 by 0.25 in. in the longitudinal, radial, and tangential directions, respectively were prepared from a straight-grained, freshly cut log of eastern black spruce. They were lightly abraded against 600-grit emery paper under water to provide smooth surfaces. Each sample was then placed, in turn, in the cleavage apparatus as shown in Fig. 10, and supported in an upright position by lowering the tip of the wedge against its upper surface. The wedge was then lowered slowly, in stages, by turning the handle and at the end of each stage the crack length, c, and the displacement, δ, were measured using a cathetometer. Between 20 and 30 readings of c and δ were taken for each specimen, and data were rejected when the crack deviated more than a twentieth of the width of the specimen from the centerline.

The precision of the displacement measurement was ± 0.001 cm., and the precision of the crack-length measurement was ± 0.02 cm. The lower precision of the crack-length measurements was due to the difficulty of precisely locating the crack tip. For instance, since it was rarely possible to prepare such a long specimen of wood having its grain exactly parallel to the sides of the specimen, a situation was sometimes encountered in which the crack tended to jump from one annual ring to the next. This resulted in a mass of loosened fibers spanning the crack and obscuring the crack tip.

The data were treated by employing a rearrangement of equation (9) in the form:

$$\left(\frac{3}{256}\frac{E}{P}\frac{\delta^2}{c}\right)^{1/3} = \frac{c}{b} \qquad (10)$$

and noting that $I = nb^3/96$, where b = total width of specimen. A plot of $(\delta^2/c)^{1/3}$ vs. (c/b) should then yield a straight line passing through the origin, if P remains constant. In fact, a curve is obtained at low values of c/b, since under these conditions the beam theory does not hold. For higher values of c/b the curve approaches a straight line asymptotically. The slope, m, of the asymptote is given by:

$$m = \left(\frac{3}{256}\frac{E}{P}\right)^{1/3}$$

whence:

$$P = \frac{3E}{256\, m^3} \qquad (11)$$

It is thus also necessary to measure the bending modulus of each specimen in order to obtain a value for the effective surface energy. One half of the fractured specimen was taken, and the fractured edge planed smooth. It was supported symmetrically on this edge at two points 14 in. apart and progressively loaded at the center. The respective deflections of the center of the beam were measured by a cathetometer. The slope of the load–deflection curve was measured and the bending modulus (or Young's modulus in the longitudinal direction) was then determined from the slope. Figure 11 shows a typical plot of load vs. deflection. The relation is seen to be linear over a deflection range encompassing the range of deflections employed in the cleavage experiments. There was some variation between the values of the bending moduli obtained for the various specimens, but all values fell within the range (6–11) $\times 10^{10}$ dynes per sq. cm., in agreement with values reported in the literature (*7*).

Figure 12 shows a typical plot of $\left(\frac{\delta^2}{c}\right)^{1/3}$ vs. c/b. An average value of the effective surface energy of 1.3 $\times 10^5$ ergs per sq. cm. was obtained for several experiments of this type.

Benbow and Roesler have shown (*9*) that some measure of the validity of the energy criterion of fracture may be drawn from the results of experiments of this type in which the width of the specimen, b, is varied. For specimens of different width there will be differences between the stress at any characteristic point, if P is constant. Conversely, if similar values of P are obtained from experiments in which samples of different width have been employed, there is some justification for believing that the energy criterion of fracture holds.

Samples of half the width (1.5 in.) were therefore employed in a subsequent series of experiments, and it will be noted from a typical plot of the data shown in Fig. 13 that larger values of c/b were obtained with the narrower samples, providing a better approximation to the asymptotic conditions. An average value of the effective surface energy of 1.6 $\times 10^5$ ergs per sq. cm. was obtained. In view of the differences already obtained between samples this increase is not regarded as significant.

TENSILE TEARING OF WOOD

The energy criterion for fracture states that the decrease in strain energy is equal to the increase in surface energy. This may be written as:

$$-\left(\frac{\partial U}{\partial c}\right)_\delta = \left(\frac{\partial V}{\partial c}\right)_\delta = 2nP \qquad (12)$$

Thus, $-(\partial U/\partial c)_\delta$ gives an almost direct measure of the effective surface energy.

Rivlin and Thomas (*10*) have developed a graphical method for treating tensile force–displacement data to obtain this differential quantity, and have applied the method to various forms of tearing of vulcanized rubbers. They showed that under certain conditions, fracture in these materials occurs according to the energy criterion.

This graphical method of evaluation could be applied to the data obtained above for the tensile fracture of wood initiated at centrally located cracks. However, as a matter of further interest, it was applied to the tensile tearing of wood initiated at edge cracks. Specimens having dimensions 4 by 3 by 0.375 in. in the longitudinal, radial, and tangential directions, such as shown in Fig. 14, were prepared in the normal manner from a single bolt of black spruce. In each specimen a small slit was cut along the grain from the center of one of the longitudinal–tangential edges. A sharp wedge was

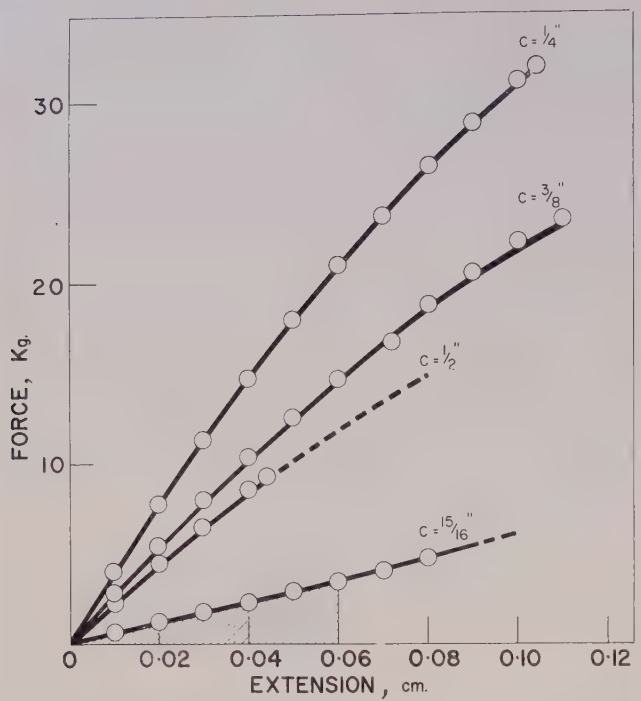


Fig. 15. Force-extension curves prior to fracture for the tensile straining of green spruce specimens containing edge cracks of various lengths in the longitudinal–tangential plane

Areas, such as the one shaded, represent the strain-energy content of the wood at the appropriate extension

inserted in the slit and by applying a force the specimen was partially cleaved. Each specimen was then trimmed from both longitudinal edges to a final longitudinal dimension of 1.25 in. in such a way that it included an edge crack of predetermined length.

The specimens were then strained, in turn, on an Instron tensile tester at a crosshead speed of 0.05 cm. per min. The tensile force was applied normally to the direction of the crack, and straining continued until

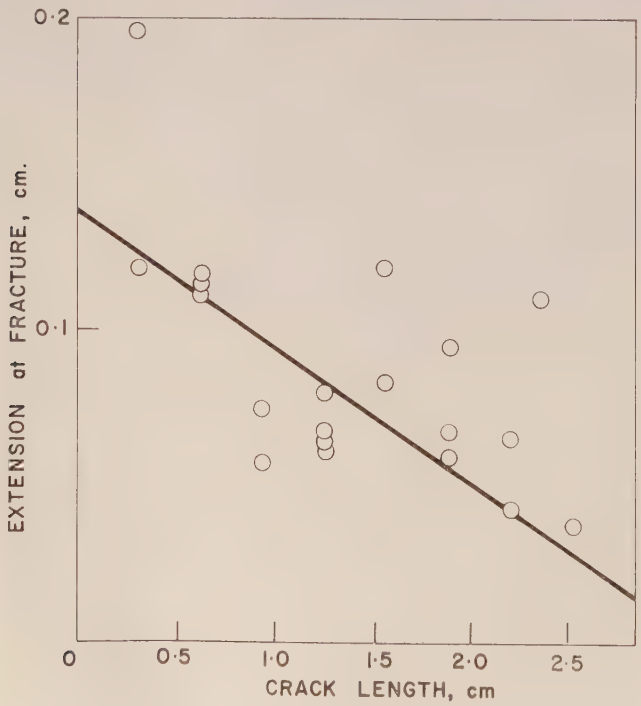


Fig. 16. Extension at fracture as a function of crack length for tensile straining of specimens containing an edge crack

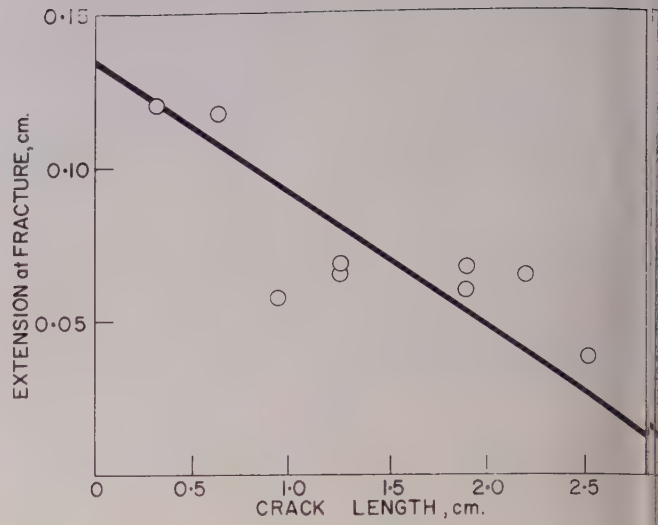


Fig. 17. Selected data from Fig. 16

The data selected were those where the fracture surface did not show gross deviation from the longitudinal–tangential plane.

catastrophic fracture occurred. It will be noted that there is an asymmetric stress concentration in the specimen with only one edge crack. From the Instron tensile force–displacement curves, examples of which are given in Fig. 15, two further sets of curves were constructed:

1. Curves of displacement-at-fracture as a function of crack length. Figure 16 shows the results obtained from a typical set of experiments. These data show considerable scatter. Since all fractures in a single

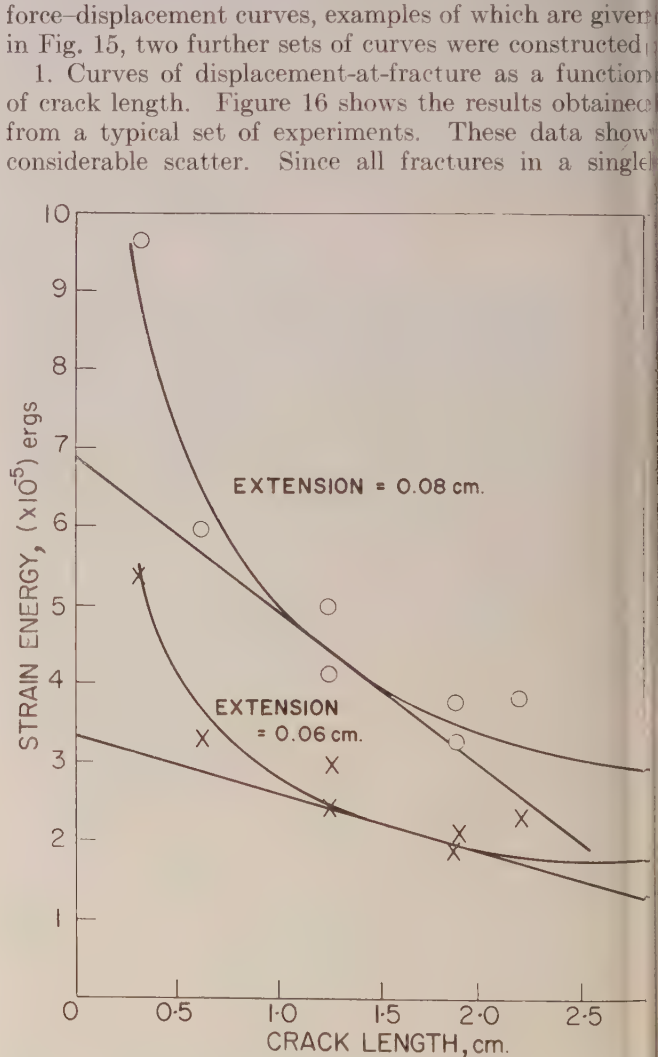


Fig. 18. Plot of strain energy as a function of crack length at two extension values

This graph was constructed from Fig. 15. The effective surface energy is calculated from the tangents to these curves at crack lengths corresponding to these extensions at fracture (taken from Fig. 17).

series were included in this plot a close examination of the fracture surfaces of the fragments was made in order to determine whether there was any gross departure from the tangential–longitudinal plane in which the fracture was initiated. It was found that parts of the fracture surface often curved away from the initial plane of fracture. In fact, some portions of the fracture surface repeatedly turned through an angle in excess of 45° from the longitudinal–tangential plane in zig-zag fashion. Fractures in this category were rejected and all the rest were termed tangential fractures. Following this differentiation, the data were replotted in Fig. 17.

2. Curves of strain energy, U, at an arbitrarily chosen displacement, δ, were plotted as a function of

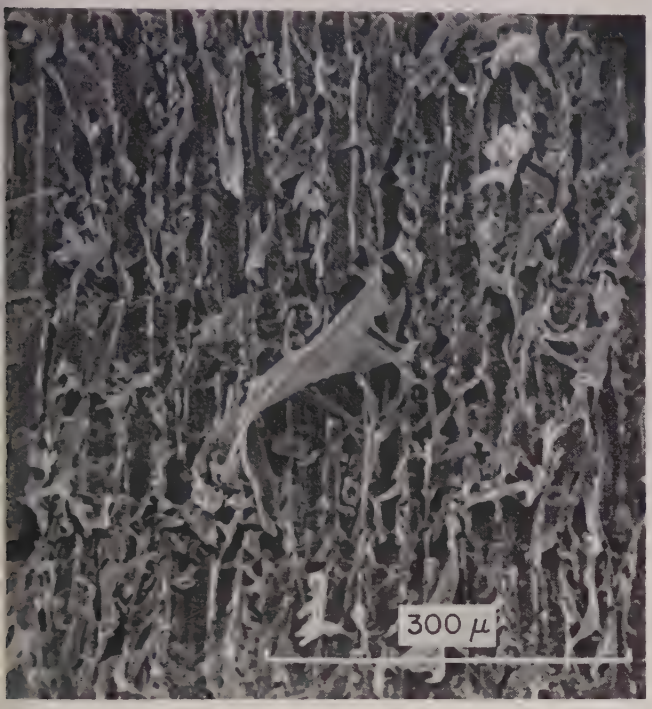


Fig. 19. Electronmicrograph of longitudinal–tangential fracture surface obtained in tensile fracture of green spruce at room temperature

Surface damage is quite extensive, and much of the apparent debris is due to complete fracture through the tracheid walls, leaving loose ends dangling from the surface.

Fig. 20. Closeup of center of field of view of Fig. 19

The damage can be seen in more detail, showing extensive fragmentation of tracheid walls. Ray cells, to the left of center of the large damage fragment, have been completely fractured across in the plane of the neighboring fracture surface.

Fig. 21. Radial–longitudinal fracture surface obtained under same test conditions quoted for Fig. 19

In the lower right corner a whole series of tracheids have been fractured completely through their walls. Some selected areas look relatively free from damage at this resolution.

Fig. 22. Higher resolution views of an area of ray crossings

The ray cells appear to have been stripped out in a relatively clean fashion.

crack length, c. The requisite strain energy was the area bounded by the tensile force–displacement curve and the displacement axis to the chosen displacement coordinate. A typical area is shown shaded in Fig. 15. Two separate displacements of 0.06 and 0.08 cm. were chosen, and the areas were measured by a planimeter. Observing the above-mentioned differentiation, plots of U_δ vs. c for the two displacements were constructed and are shown in Fig. 18.

The crack length corresponding to the given displacement is then measured on the corresponding graph in Fig. 17, and the tangent is drawn to the plot of U_δ vs. c at this crack length. The slope of the tangent gives the required value of $(\partial U/\partial c)_\delta$, and hence P.

An average value of 1.2×10^5 ergs per sq. cm. was obtained in this manner for the effective surface energy. The scatter in these results indicates that an inclination of the fracture surface to the longitudinal–tangential plane causes proportional changes in the amount of surface energy, and the graphical method is very sensitive to such changes. It also suggests that such inclinations in the fracture surfaces may have partially

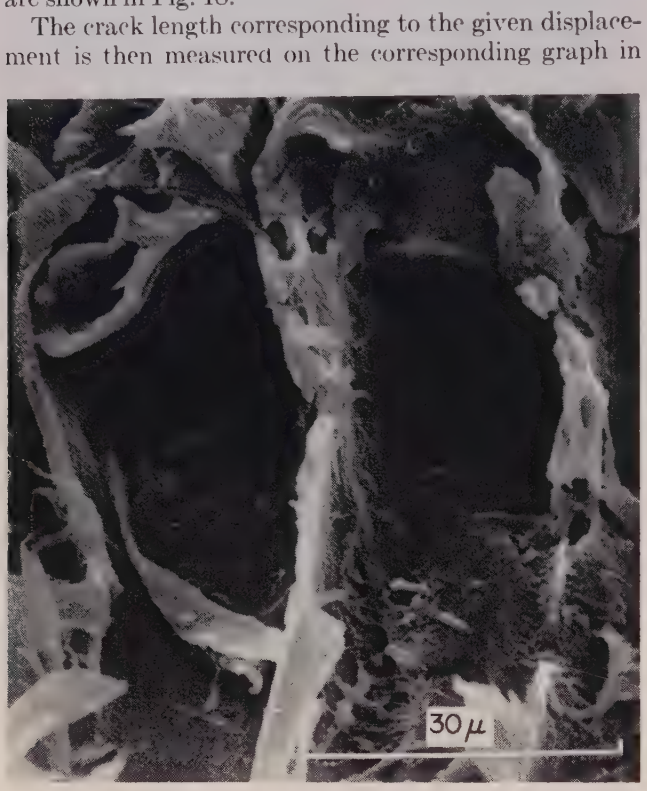


Fig. 23. View of complete split across walls of two contiguous tracheids

Some debris can be seen inside the tracheids.

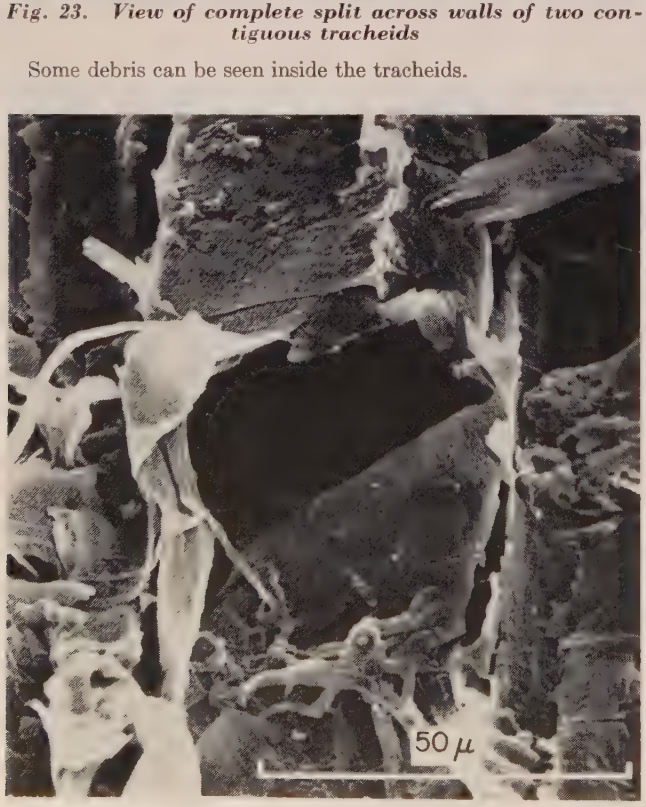


Fig. 24. Partial split across the wall of a tracheid

Extensive damage is evident throughout the whole field.

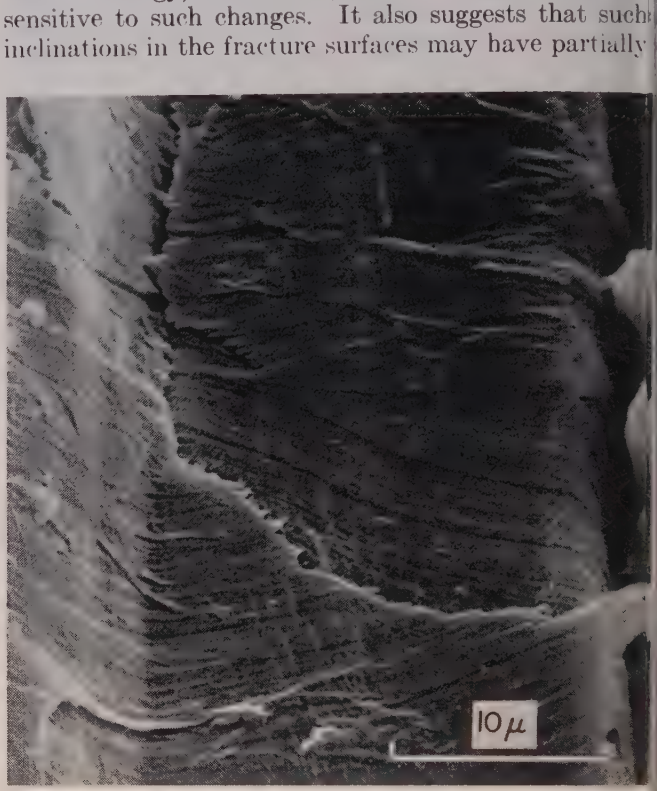


Fig. 25. High resolution view of tracheid wall which appears relatively undamaged on lower resolution pictures (see, e.g., Figs. 21 and 22)

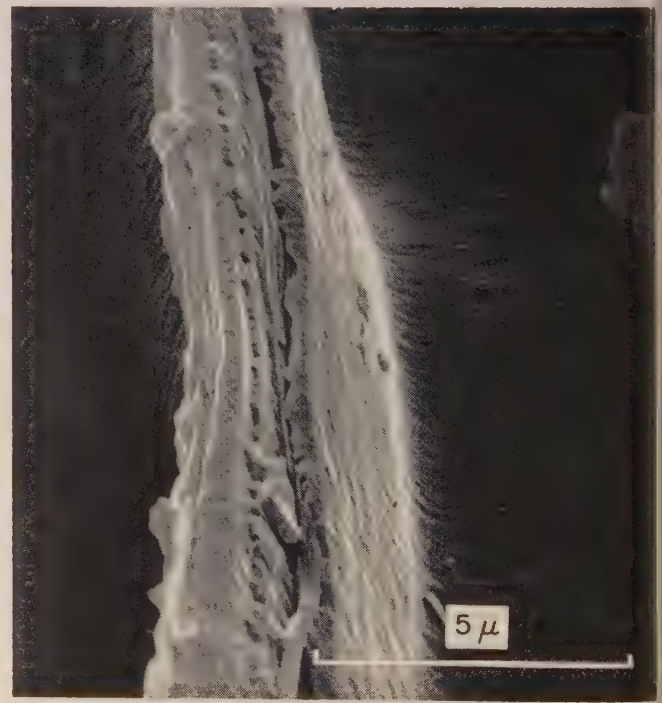


Fig. 26. Longitudinal section of complete split along common wall of two neighboring tracheids (see text)

occurred in the cleavage fracture and tensile fracture from centrally located cracks.

MICROSCOPIC EXAMINATION OF FRACTURE SURFACES

Values of the effective surface energy for the fracture of wood, quoted above, have been calculated on the assumption that the fracture surface is substantially plane. These surfaces have been examined in the electron microscope, and some of them are shown in Figs. 19 to 31.

Figure 19 gives a general view of a fracture surface in the longitudinal–tangential plane. This particular surface was obtained for tensile fracture at room temperature initiated at a centrally located crack. The strain rate prior to fracture was 2×10^{-4} sec.$^{-1}$. This view is typical of fracture surfaces in this plane for both types of tensile fracture and also for low speed cleavage. A higher resolution picture of the center portion of this field is given in Fig. 20, where the nature of the damage can be seen in more detail.

A typical fracture surface in the radial–longitudinal plane obtained under similar test conditions is shown in Fig. 21, and Fig. 22 is a closeup view in this plane showing an area of ray crossings. It is quite apparent that considerable surface development has occurred on both planes.

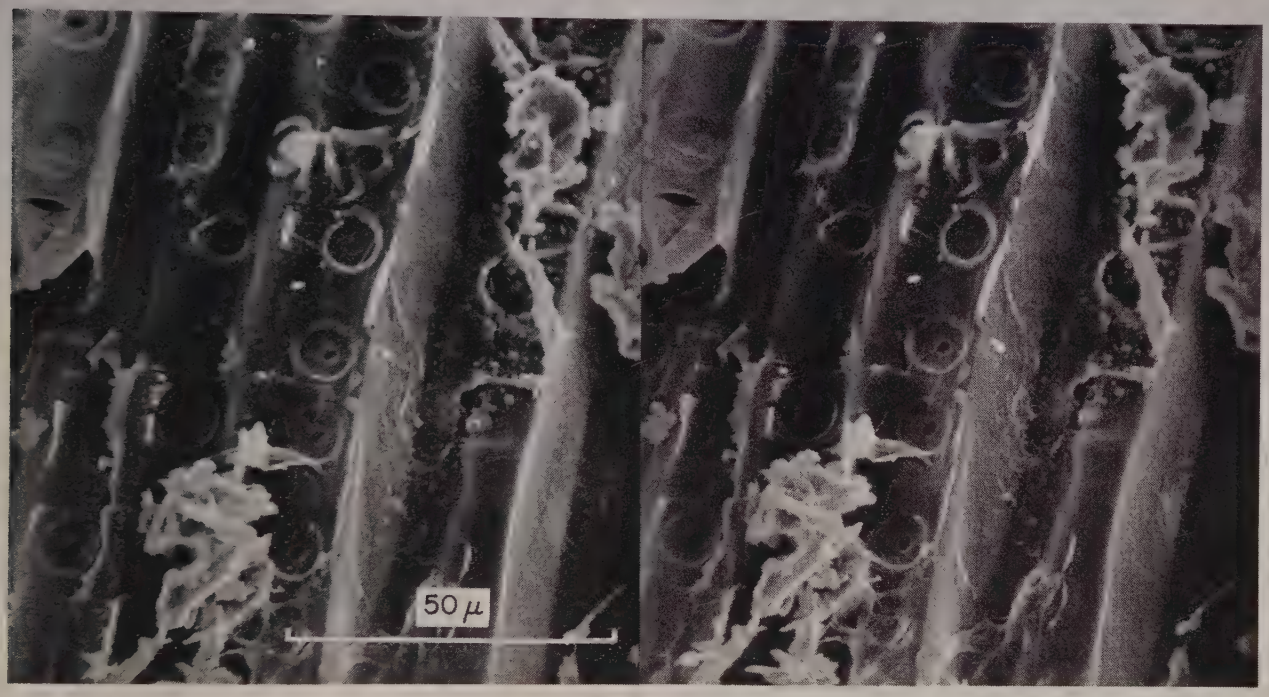
Examination of all the pictures taken shows that the fracture surfaces are far from plane and that fracture occurs in many cases across the complete walls of both tracheids and ray cells. Figure 23 shows such a complete fracture across the walls of two contiguous tracheids, while Fig. 24 shows a tracheid wall which has been only partially split.

Often there are areas of a tracheid wall which appear relatively undamaged on low-resolution pictures. Such an area examined in high resolution, as in Fig. 25, reveals a considerable extent of submicroscopic surface.

Figure 26 is a view of two contiguous tracheids which have been split in the plane of the picture. Running down the centre of the picture is the longitudinal section of two complete tracheid walls, and these fall away on either side of the picture into the lumina of the tracheids. This is considered a drastic split and must require a relatively high localized energy consumption, and yet it occurs in a relatively simple fracture process. Thus, even in such simple fractures the energy requirements are not distributed uniformly over the fracture surface.

In view of the submicroscopic detail exposed in the creation of these new surfaces which, of course, contributes much more to the total area development than the larger and more easily discernible discontinuities, it would be difficult to estimate the increase in surface area from direct examination of micrographs and it will be necessary to employ physical techniques such as low angle x-ray scattering or refined gas adsorption measurements. When this has been accomplished, true values of the effective surface energy should be obtained.

When samples maintained at a temperature close to 100°C. were fractured, the nature of the fracture surfaces was altogether different from those obtained for fracture at room temperature. Examples of this are shown in Figs. 27 to 31. Although there was some fracture across the tracheid walls, the fracture surfaces were generally quite smooth. Most of the fracture surface lies in the region of the compound middle lamella, and it is often of a stepped nature as seen in the stereo



Figs. 27 and 28. Stereo pair of longitudinal–tangential fracture surface obtained when specimens are fractured at a temperature close to 100°C.

The surface is relatively smooth, and in stereo, the stepped nature of the surface is evident.

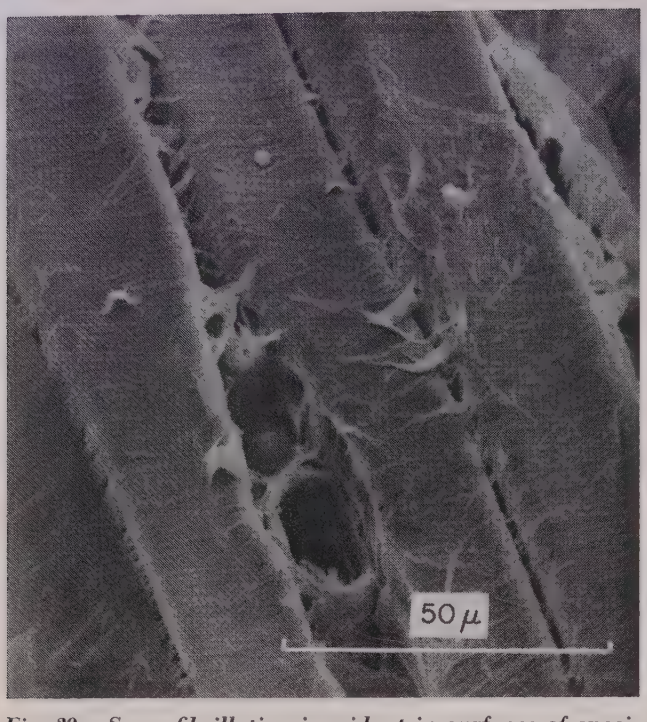


Fig. 29. Some fibrillation is evident in surfaces of specimens fractured hot, but only over relatively small areas

pair, Figs. 27 and 28. Where tracheids are partially removed from the surface, they are not damaged extensively as in room temperature fracture but are more nearly whole tracheids with relatively smooth surfaces. It would be very informative to have some measure of the lignin content of these fracture surfaces since their appearance suggests fracture through a layer having a high content of plasticized lignin. Goring has recently shown that extracted wet lignins are plastic in this temperature range (*11*), and this may account for the smoothness of the fractured surfaces.

The development of surface is obviously smaller in the specimens fractured at high temperature than in those fractured at room temperature. Since the measured effective surface energy was found to be the same at both temperatures, the corrected effective surface energy must be larger for the high temperature fracture.

It should be emphasized that the validity of the Griffith equation for fracture in a heterogeneous material such as wood which yields rough fracture surfaces represents only a first order approximation, which may be employed to detect rather large changes in fracture behavior. The distribution of strain energy in wood just prior to fracture must be far from uniform, and the complex stress distribution in the region of the crack susceptible only to experimental determination.

The change in the rate of release of strain energy as the crack proceeds must be influenced much more strongly by the excessive surface roughness and the heterogeneous nature of the wood than by such factors

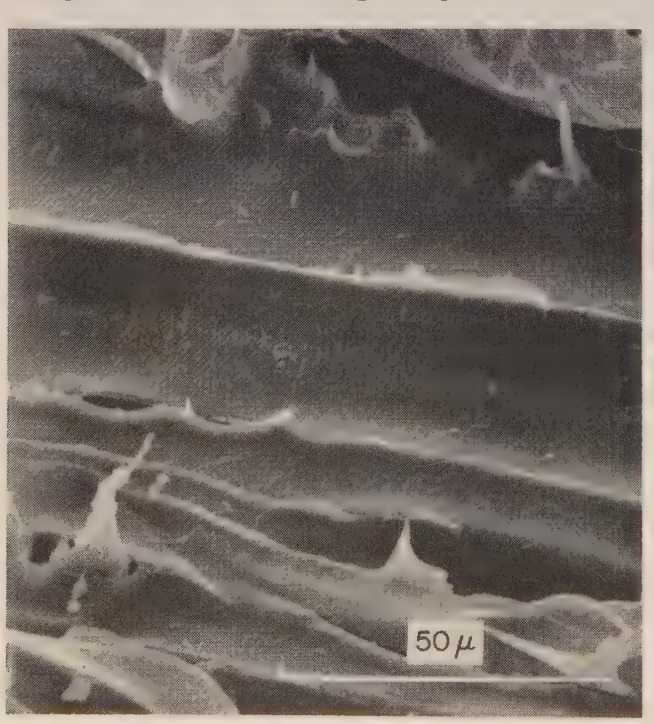


Fig. 30. The surface of specimens fractured hot are generally as seen in this picture

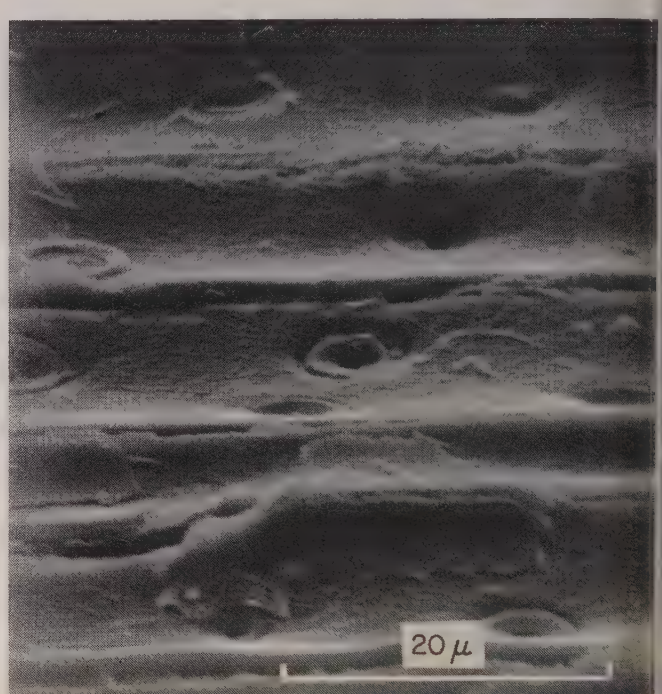


Fig. 31. Another typical view of a surface fractured hot

The surface is relatively smooth and it is believed that the crinkling results from air-drying the specimen before it is metallized for microscopic examination.

as the end effect arising at high ratios of crack length-to-specimen width. This latter correction, incidentally, has been derived by Westergaard (*12*), who considered plane fracture surfaces. In the present experiments this correction corresponds to a reduction of 8% in the observed tensile stress for the longest cracks which were employed.

Despite these departures from the conditions assumed by Griffith in his original derivation, it has been shown experimentally that there is a definite major direction of crack propagation which occurs even when the fracture is rough, and the various measurements of effective surface energy obtained through use of the criterion are mutually consistent. Examination of the fracture subsurface shows that the zone of damage is restricted to a very small depth. This supports the inference drawn from the applicability of the modified Griffith equation, that gross plastic deformation only occurs near the surface of the crack.

IMPLICATIONS OF THESE MEASUREMENTS TO THE THEORETICAL EFFICIENCY OF MECHANICAL PULPING

Calculations of the theoretical efficiency of mechanical pulping processes have been made (*13*, *14*) using various values for the specific surface energy, on the assumption that these processes represent the attrition of a solid piece of wood into small fragments and the consequent energy-consuming production of surface area. A similar calculation has been made for the theoretical efficiency of beating, a process which is often regarded mechanistically as being closely allied to mechanical pulping (*15*).

If the surface area per unit dry weight of one of the many complex mixtures of fibers, parts of fibers, and fines, which constitutes a good papermaking pulp, is known, then it is possible to calculate a value for the absolute minimum energy required to produce that pulp. This value is the product of the surface free energy of the wood and the surface area per unit dry weight of the pulp, and may be regarded as a theoretical efficiency. Although the surface free energy of wood has never been measured, the value of 600 ergs per sq. cm. estimated by Campbell (*13*) is of the correct order of magnitude. The theoretical efficiency calculated from this figure demands that no plastic-deformation energy be dissipated in the idealized attrition process.

In practice the efficiency problem resolves itself into one of producing an acceptable papermaking pulp with a minimum expenditure of plastic-deformation energy. Measurements such as those given in this paper, and similar ones recently reported by Lamb (*14*), are primarily directed toward determining general relationships for the plastic-deformation energy involved in fracture in terms of such parameters as rate of strain, temperature, and various methods of applying the strain. Since the production of mechanical pulp involves various types of fracture, and any fracture involves relatively large deformations, it is inevitable that some plastic-deformation energy be dissipated in pulping a viscoelastic material like wood. It should be pointed out that even when the general relationships for the plastic-deformation energy involved in wood fracture are obtained they may provide only a guide to the most efficient method of mechanical pulping, since acceptable mechanical pulp is not any arbitrary attrition product of wood characterized solely by its surface area. Mechanical pulp consists of wood fragments of various dimensions, and these dimensions play a role of primary importance both in the manufacture and in the properties of the final paper. It is easy to conceive two pulps having equal surface area but having a different distribution of sizes and shapes and hence different papermaking characteristics. In newsprint, for instance, it has long been recognized that the flexibility of the larger fragments is an important papermaking property. The mechanical means by which flexibility is induced into a naturally stiff fiber is little understood, but whatever the process, it will undoubtedly consume energy which may not appear as accessibly measurable surface energy, and some plastic work will be lost in the process.

Complex attrition processes by which wood is converted into a papermaking pulp, must in the final analysis consist of a multiplicity of simple fractures throughout the material. Investigation of the effects of such parameters as temperature, moisture content and rate of straining on simple fracture processes such as outlined in this paper should therefore lead to a better understanding of the parts they play in more complex processes.

CONCLUSIONS

The tensile and cleavage fracture of spruce parallel to the grain has been shown experimentally to obey a modified Griffith form of equation, to a first approximation. Thus, the criterion for fracture of spruce is that the rate of release of strain energy in crack formation must be at least equivalent to the sum of the surface free energy and plastic work associated with the formation of new surface in the neighbourhood of the crack.

Since the fracture surfaces are far from planar, a true value of the effective surface energy, P_e, cannot be derived until an accurate measure of the surface area is made. At strain rates prior to fracture, through the range 2×10^{-4}-2×10^{-3} sec.$^{-1}$, values of the order of 1×10^5 ergs per sq. cm. were obtained for the effective surface energy, P. Thus, if it is assumed that the true surface free energy is of the order of 1000 ergs per sq. cm. and the ratio of the real to the apparent surface area is r, a simple calculation, which ignores the perturbations of the stress field due to the surface roughness and hence the rate of release of strain energy in cracking, shows that unless $r \gtrsim 100$, plastic work is dissipated in the fracture. Electronmicrographs of the fracture surfaces indicate that damage involving the dissipation of considerable plastic work has occurred. It would be difficult to estimate the true surface area, even qualitatively, from the micrographs but it would not appear that r has a value anywhere close to 100.

Preliminary results of tensile fracture of green wood at 100°C. indicate that, at that temperature, fracture occurs mainly through the compound middle lamella, and appears to be aided by plasticization of the lignin under these conditions. However, it is interesting to note that the plastic work, p_e, dissipated in fracture at 100°C. exceeds that dissipated at room temperature.

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Adhesion to Fibrous Materials

J. J. BIKERMAN

The mechanism of adhesion to fibrous materials is reviewed. Adhesion of coatings or glues to fibrous materials usually is a mechanical, "hooking," effect. This is proved, for instance, by the insensitivity of the bond to impurities causing weak boundary layers. The experiment allegedly proving the existence of specific adhesion between glue and fiber can be given a better explanation. In those instances in which no hooking and embedding occur, the adhesion to fibrous materials is analogous to the adhesion to nonporous solids. The rate of formation and setting of adhesive joints with fibrous adherends is determined by the shape and size of pores in the adherends, their wettability and their tendency to swell, and by the viscosity (or consistency) and the surface tension of the adhesive. These relations can be expressed in quantitative terms. The notion of the minimum depth of penetration needed to achieve maximum resistance to splitting is introduced.

I. THE NATURE OF ADHESION

The breaking stress of an adhesive joint (abbreviated to *adhint* in the following) between two nonporous solids generally depends first of all on whether a weak boundary layer (which may simply consist of air) is or is not present between the adhesive and the adherend. If such a layer is present, rupture occurs in it and requires an effort small compared with that needed to break the adherend or the adhesive. If no zone of weakness exists along the adherend-adhesive interface, then rupture proceeds in the bulk of the weaker of the two materials and breaking stress is related to the (tensile or shear) strength of this material; the actual relation between strength of adhint and strength of its components being determined by residual stress and by stress concentrations in the adhint (*1*).

When the adherend is an assembly of fibers, e.g., a mat or a fabric, a third type of adhint is encountered. In it, the solidified adhesive acts as a multitude of hooks, on which mat or fabric filaments are suspended. When the hooks and the filaments are pulled in the opposite directions, either the former or the latter must break before parting is possible. Because the interlocking is purely mechanical, many impurities on the fiber surface, which would be disastrous in a metal-adhesive-metal adhint, prove to be irrelevant. It is clear that for a dirty fiber it would be just as difficult to get off the hook as for a clean one.

Probably, the majority of the paper-adhesive combinations belongs to this third type. This is shown not only by the possibility of gluing paper without carefully cleaning it, but also, and above all, by microphotographs of cross sections of paper coated with an adhesive (as in remoistening tape) and of paper-adhesive-paper and cardboard-adhesive-cardboard adhints. Penetration of glue between paper fibers and its solidification around the fibers are so unmistakably seen that it is difficult to understand why a need for a different explanation was felt.

The experiment, on which the alternative explanation is based, is as follows. A wood surface is coated with an aqueous adhesive, which fills the pores. After setting, the solidified glue is found clinging to the pore wall. Why is the glue not suspended in the middle of the pore? In other words, why contraction associated with setting progressed toward the wall rather than away from it? The answer originally given was that a specific attraction between wood and glue existed, and it was further claimed that this attraction was more important than the hooking mentioned in the penultimate paragraph.

However, a more plausible answer is possible. As long as gravitation is unimportant, the solid phase after setting is likely to be situated where the first nuclei formed. Nuclei form first in the region of the highest supersaturation. When an aqueous adhesive is introduced into a pore of relatively dry wood, water is taken up by the pore walls; hence, the degree of supersaturation is highest at the walls, and separation of the solid phase takes place there first. Thus, there remains no convincing proof for a specific attraction or for the importance of the latter.

The hooking effect may be expected to be predominant as long as the pores between the fibers are open to the outside, i.e., also to the adhesive. Many fibrous materials are coated with, e.g., a layer of lacquer so that their surface is not fibrous at all; in these cases the rules of the adhesion to nonporous surfaces would be valid.

II. THE RATE OF FORMATION

In the third type of adhints, as defined in section I, a satisfactory bond is achieved when the adhesive penetrates so far in the fibrous material (e.g., cardboard) that, after setting, a breaking force causes separation between cardboard and cardboard only; presumably a deeper penetration would not enhance the breaking stress of the adhint.

Let this depth of penetration be z_0 and, for simplicity, assume the pores to be very long and narrow slits between two parallel walls; the slit width is δ, see Fig. 1. We assume also that the adhesive is a Newtonian liquid and that gravitation may be disregarded. If the variable distance of the meniscus from the upper end of the pore is z, then:

$$\frac{dz}{dt} = \frac{\delta^2}{12\eta} \cdot \frac{dP}{dz}; \qquad (1$$

t is time, η viscosity of the adhesive, and P is the pressure whose gradient causes the downward advance of the liquid. Equation (1) is well known and can easily be derived. In our instance P is the capillary pressure. For a long and narrow pore:

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$$P = \frac{\gamma}{R}, \tag{2}$$

if γ is the surface tension of the adhesive and R the radius of curvature of the meniscus. This R is a function of the advancing contact angle θ_A and the width δ, as shown in Fig. 2:

$$0.5\delta = R \cos \theta_A. \tag{3}$$

Thus:

$$P = \frac{2\gamma \cos \theta_A}{\delta} \tag{4}$$

and

$$\frac{dP}{dz} = \frac{2\gamma \cos \theta_A}{\delta z} \tag{5}$$

Introducing (5) into (1), we obtain:

$$dz/dt = (\delta/6\eta z)\gamma \cos \theta_A$$

that is

$$2z \cdot dz = \frac{\delta\gamma \cos \vartheta_A}{3\eta} dt. \tag{6}$$

Integration between $z = 0$ and $z = z_0$ gives:

$$z_0^2 = \frac{\delta\gamma \cdot \cos \theta_A \cdot t}{3\eta}, \tag{7}$$

if time is reckoned from the moment of application of the glue. Equation (7) rewritten as:

$$t = \frac{3\eta z_0^2}{\delta\gamma \cos \vartheta_A}, \tag{8}$$

permits us to estimate the time needed to produce a satisfactory bond. Experiments designed to test equation (7) are in progress. In the meantime, its components can be discussed.

Presumably, z_0 is smaller the stronger the fibers and the denser the board. But in a dense board also δ would be smaller; thus, it is impossible to predict whether a greater density of the board will result in a longer or shorter t. The difference between the γ values of commercial adhesives is not very great; thus, as far as the adhesive is concerned, its viscosity η and its effect on θ_A are decisive. It is clear that η should be small if t is to be short, but low viscosity should not be achieved at the expense of the rate of setting, see below. The angle θ_A should be as small as possible, that is, the adhesive should perfectly wet the fibers; but, naturally, the diminution of θ_A should be attained without impairing the other qualities of board and adhesive. Generally, θ_A is small when fibers swell in the adhesive, but swelling would reduce δ.

Equation (8), which postulates prismatic pores and Newtonian liquids, obviously cannot be expected to provide correct numerical results for industrial fibrous materials (whose pores have irregular shapes) and industrial coatings and adhesives (which very rarely have viscosities independent of the rate of shear); but the mathematical treatment given above is useful not only because it provides semiquantitative answers but also because it makes the physics of phenomenon clear.

III. THE RATE OF SETTING

If a piece of paper is coated with a liquid adhesive, another piece of paper is placed on the latter, and peeling at once started, the separation will often

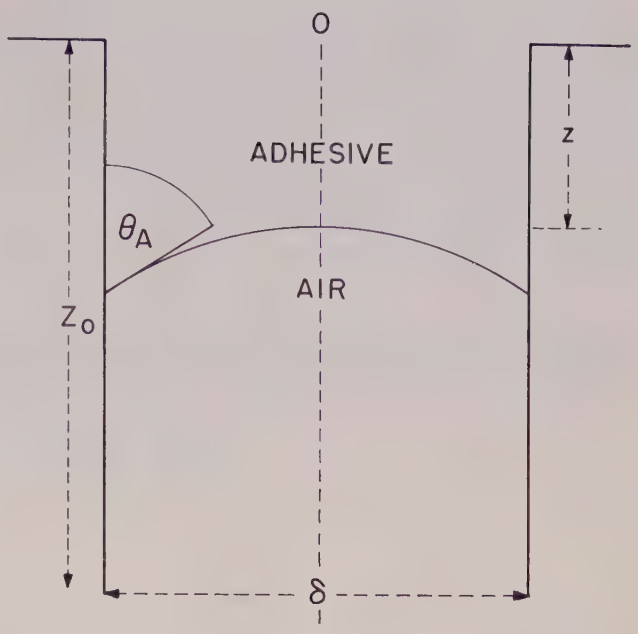

Fig. 1. Advance of liquid in a pore

θ_A is the advancing contact angle, δ is the pore width.

proceed in the liquid, and no fibers will be torn out of the paper. Thus, the state described in the first paragraph of section II is not immediately achieved. The time needed to reach this state is the setting time of the adhesive. If the adhesive sets because of cooling or because of a chemical reaction, the time of set may be similar for a fibrous and a nonporous adherend, but if setting results from the removal of solvent or dispersion medium, the rate of set usually will be found greater when the adherend is of a fibrous nature.

If both adherends are continuous solids, which do not swell in the adhesive (e.g., two metals joined by means of a polymer), the solvent cannot escape as a liquid, cannot diffuse into the adherends and can evaporate at a very slow rate only. When both adherends are fibrous, evaporation is unobstructed, the liquid can spread in the adherends by capillary rise, and the molecules of the adhesive can diffuse along the fiber surface and in the swollen fibers.

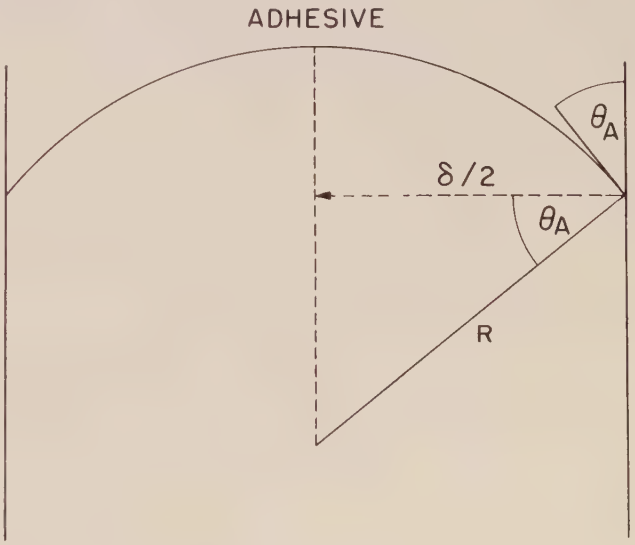

Fig. 2. Relation between the radius of curvature, R, and pore width, δ

The rate of capillary spreading is governed by equations of type (8), and the rate of surface diffusion (*2*), and of diffusion in gels also has been investigated. Thus, the difference between the time of set in a mat or a fabric and the analogous time for an adhesive between two metals can be accounted for, if the relevant properties of the fibrous adherend (porosity, wettability, rate of swelling, and so on) and of the adhesive (surface tension, viscosity, and so on) have been measured.

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Heat Transfer in Porous Bodies at Various Temperatures and Moisture Contents

LENNART HERMINGE

To determine the thermal conductivity of porous materials an apparatus based on the dynamic Angstrom method was used; i.e., the propagation velocity of a heat wave in the material was measured. From the propagation velocity the thermal conductivity can be calculated when the density and specific heat of the material are known. The thermal conductivities of two beds made of glass-fiber fabric were measured at three different mean temperatures for each bed and at saturation degrees ranging from zero to unity. The results obtained were used to check a correlation equation which gives the thermal conductivity of a porous material as a function of temperature and moisture content when the thermal conductivites of the material in the dry and fully saturated states are known.

NOMENCLATURE

A	= pore area, cm.^{2}
a	= $\sqrt{\pi/\alpha\theta_0}$
b	= the fraction of total available pores which contain water
C_e	= effective specific heat, cal./g. °C.
C_p	= specific heat, cal./g. °C.
D	= vapor diffusivity, cm.^{2}/sec.
d	= distance between measuring points, cm.
f	= phase difference, sec.
G	= rate of vapor transport, g./sec.
g	= length in Fig. 4
h and s	= parameters
k	= thermal conductivity, cal./cm. sec. °C.
k_1	= thermal conductivity defined by equation (15), cal./cm. sec. °C.
k_2	= thermal conductivity defined by equation (16).
k_e	= effective thermal conductivity, cal./cm. sec. °C.
L	= length, cm.
M	= molecular weight, g./mole
P	= power, watt
p	= total pressure, g./cm.^{2}
p_s	= partial pressure, g./cm.^{2}
Q	= heat flux, cal./sec.
R	= gas constant, cal./mole °K.
R_e	= electrical resistance, ohm
r	= length in Fig. 4
T	= absolute temperature, °K.
t	= temperature coordinate, °C.
t_0	= surface temperature, °C.
t_M	= mean temperature at which the thermal conductivity was determined, °C.
t_{0M}	= maximum amplitude of the temperature variations on the surface, °C.
V	= voltage
w	= propagation velocity of the heat wave, cm./sec.
x	= coordinate in Fig. 1
α	= thermal diffusivity, cm.^{2}/sec.
ϵ	= void fraction
ϵ_w	= fraction of void filled with water
ρ	= density, g./cc.
ρ_e	= effective density, g./cc.
θ	= time, sec.
θ_0	= periodic time, sec.

Subscripts

a	= air
s	= solid
w	= water

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STEADY- AND UNSTEADY-STATE EXPERIMENTAL METHODS

A STEADY-STATE method for measurement of the thermal conductivity of wet, porous materials has drawbacks. A long period of time is required to attain equilibrium, during which the moisture in the material is free to move. Under influence of the temperature gradient, an uneven moisture distribution will be obtained.

One way to overcome this difficulty is to shorten the measurement time by use of an unsteady-state method. A method of this type was employed by Krischer and Esdorn (*1*), and Hatton (*2*). Both used the same basic principle: a sample of the material is brought into contact with a hot plate and by use of temperature sensing elements inserted in the sample the temperature–time relation during a short heating period is registered. By comparison of the experimentally determined temperature–time curves and the solution to the general heat equation with appropriate boundary conditions, the thermal diffusivitity, thermal conductivity, and specific heat of the material can be evaluated. This unsteady-state method can be applied to wet materials provided the temperature of the sample does not cause substantial evaporation.

The major disadvantages of the unsteady-state method are that evaluation of the experimental data is tedious and accuracy is poor relative to the steady-state method. There is also difficulty in determining the temperature at which the thermal properties were measured because the mean temperature of a sometimes large temperature range must be used. As will be shown later, the thermal conductivity of wet, porous materials is strongly temperature dependent. Furthermore, the equation with which the experimentally determined temperature-time relations are

compared, is derived assuming temperature-independent thermal properties.

THE DYNAMIC ANGSTROM METHOD

In 1861, Angstrom (*3*) first presented a dynamic method for determination of the thermal conductivity of metals at different temperatures. The method measures the propagation velocity of a heat wave traveling through a specimen. In two following articles (*4, 5*) he used the method to evaluate temperature coefficients for the thermal conductivities of iron and copper.

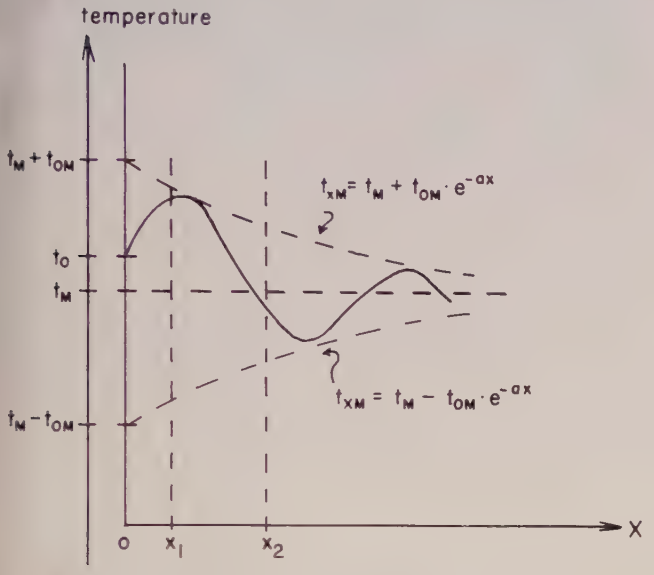

Fig. 1. Heat wave in an infinitely thick body

The Angstrom method is based on the following theory: Consider an infinitely thick body, Fig. 1, on the isothermal surface of which, at $x = 0$, the temperature, t_0, varies as

$$t_0 = t_M + t_{0M} \cos\left(2\pi \frac{\theta}{\theta_0}\right) \qquad (1)$$

To find the equation for the temperature distribution in the body, one must solve the one-dimensional heat equation:

$$\alpha \frac{\partial^2 t}{\partial x^2} = \frac{\partial t}{\partial \theta} \qquad (2)$$

subject to the boundary condition given by equation (1). A solution of equation (2) with this boundary condition is (*6, 7*):

$$t = t_M + t_{0M} e^{-ax} \cos\left(ax - 2\pi \frac{\theta}{\theta_0}\right) \qquad (3)$$

where

$$a = \sqrt{\pi/\alpha\theta_0}$$

From equation (3) it follows that the temperature variations imposed on the surface of the body will generate a heat wave in the body with wavelength $2\pi/a$ and an amplitude that decreases with e^{-ax} (see Fig. 1). Since the propagation velocity of a wave w is equal to the wavelength divided by the time for one period:

$$w = 2\pi/a\theta_0$$

or, since

$$a = \sqrt{\pi/\alpha\theta_0}$$

$$w = \sqrt{2\pi\alpha/\theta_0} \qquad (4)$$

Considering now temperature variations in the body at $x = x_1$ and $x = x_2$, it is seen from equation (3) and Fig. 1 that the temperature variations at these points are sinusoidal with period θ_0 and amplitude $t_{0M}e^{-ax_1}$ and $t_{0M}e^{-ax_1}$ at x_1 and x_2, respectively. These temperature variations at x_1 and x_2 are shown in Fig. 2.

If the phase difference between the two sinusoidal functions in Fig. 2 is f, and $x_2 - x_1 = d$, then the propagation velocity, w, of the heat wave in Fig. 1 is $d/f = w$.

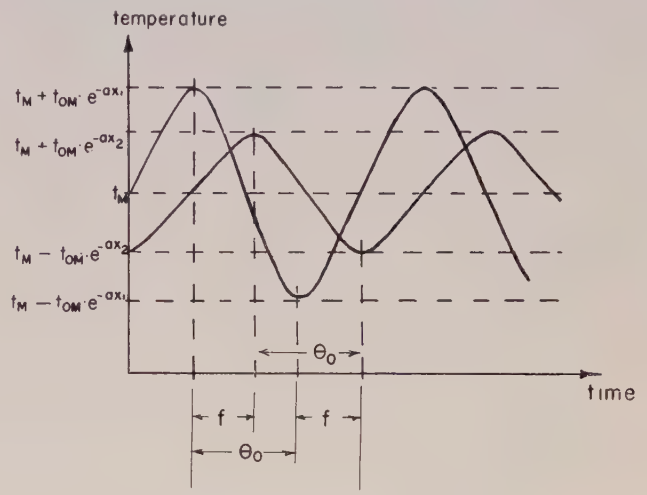

Fig. 2. Temperature variations at $x = x_1$ and $x = x_2$

Inserting this value of w in equation (4) and solving for α gives:

$$\alpha = \frac{\theta_0 d^2}{4\pi f^2} \qquad (5)$$

and, since

$$\alpha = k/\rho C_p$$

$$k = \frac{\rho C_p \theta_0 d^2}{4\pi f^2} \qquad (6)$$

Therefore, from knowledge of the phase difference between the sinusoidal temperature functions at two points a known distance apart, in a body through which a heat wave propagates, it is possible to calculate the thermal diffusivity of the body. Furthermore, knowledge of the density and specific heat of the material permits calculation of the thermal conductivity. The temperature functions at the two points can be obtained by placing temperature-sensing elements at each of the points and connecting them to a recorder.

A disadvantage of this method when used to measure the thermal conductivity of wet or dry porous materials is the long time required for each experiment. In this work the time per period θ_0 was chosen to be about 18 min. To obtain accurate results, three or four determinations of phase difference were necessary. Therefore, a total of 36 min. plus the time to achieve thermal equilibrium was required for each run.

Another disadvantage is that only the thermal diffusivity can be determined. To obtain the thermal conductivity it is necessary to know the specific heat and density of the material.

This method is advantageous because when t_{0M} is small, the thermal diffusivity is determined at a fixed temperature rather than at a mean value, since the temperature oscillates around the mean temperature t_M. In this work t_{0M} always was smaller than 2°C. Furthermore, the method does not require measurement of heat flow, and the thermal contact between heat source and sample is by no means critical to the accuracy of the result. Measurement of the phase difference between the two sinusoidal temperature functions can be quite accurate and evaluation of the primary data is simple.

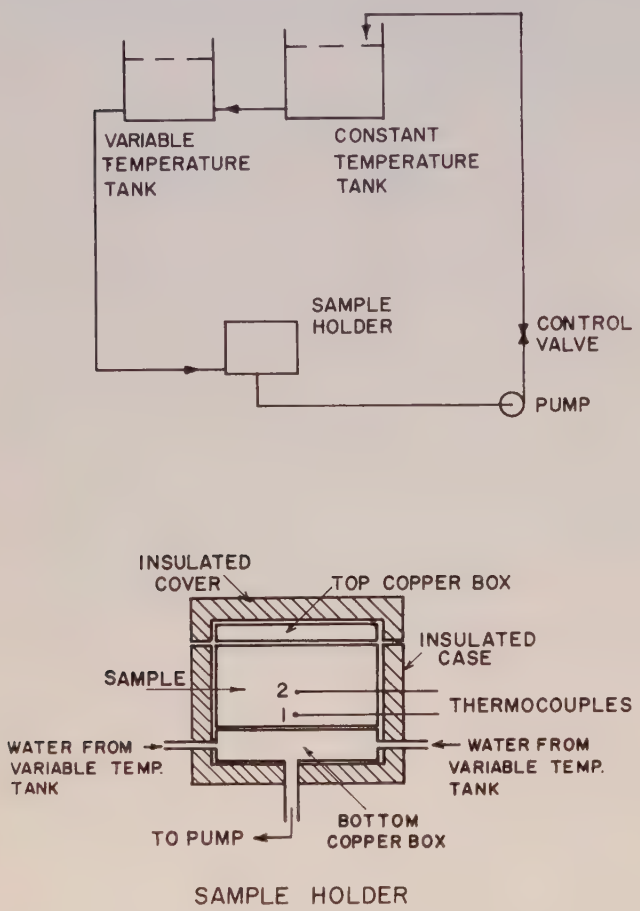

Fig. 3. Diagram of the apparatus and sample holder

The dynamic Angstrom method has been used by King (*8*) to determine the thermal conductivity of tin and copper. Starr (*9*) used a modification of the original method which measures the decrement of the heat wave instead of its propagation velocity. The decrement is proportional to thermal diffusivity and distance. He reports a value for the thermal conductivity of nickel with a probable error of 0.06%. Slides and Danielsson (*10*) have also used this method; but to achieve high accuracy for short experimental times they calculated the thermal diffusivity from both the propagation velocity and the amplitude decrement. Recently the method has been used for nondestructive measurement of the thermal conductivity of cast iron drying cylinders (*11*).

Description of Apparatus

To apply the Angstrom method to measurements of the thermal diffusivity of wet or dry porous materials the apparatus illustrated in Fig. 3 was used. The sample was placed on a copper box which was inserted in an insulated case. Another copper box was placed on top of the sample and held in place by the case. This box was maintained at a constant temperature equal to the mean temperature of the sample, t_M. Water in which the temperature varied with time as indicated by equation (1) flowed continuously through the bottom copper box. The temperature variations in this water were transmitted through the top surface of the bottom copper box to the bottom of the sample, and a heat wave which propagated through the sample was generated. Consequently, temperature variations in the sample followed equation (3). The thickness of the sample was such that the amplitude of the heat wave was nearly zero when the wave had propagated three fourths of the distance through the sample. The bottom copper box measured 12 by 12 cm. and the overall height of the sample holder was 11 cm.

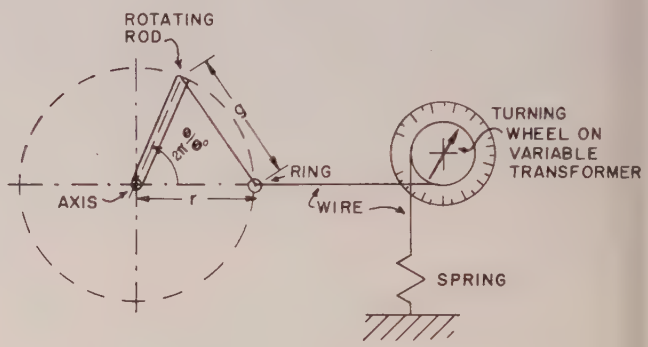

Fig. 4. The generation of a variable voltage

Two temperature-sensing elements at a known distance apart, d, were inserted in the lower portion of the sample bed. Thermopiles made of four copper-constantan thermocouples were used. The thermocouples for each point were placed in the center of the bed a small distance from each other for purposes of smoothing local irregularities. Use of four thermocouples in series eliminated need for signal amplification. The signals generated by the thermopiles were registered on a multipoint recorder.

The water flowing through the bottom copper box was pumped to a constant temperature tank. The constant temperature tank supplied water at a predetermined constant rate to the varying-temperature tank, where the sinusoidal temperature variations were generated by an electric heater.

To provide a sinusoidal temperature variation in the water, the power input to the heater in the varying-temperature tank was made sinusoidal. This was accomplished by supplying the heater from a variable transformer which was made to operate at a voltage output given by:

$$V = \frac{V_{\max.}}{\sqrt{2}} \sqrt{1 - \cos 2\pi \frac{\theta}{\theta_0}} \qquad (7)$$

With this voltage variation in the transformer output, the power on the heater varies according to the equation:

$$P = \frac{V_{\max.}}{2R_e}\left(1 - \cos 2\pi \frac{\theta}{\theta_0}\right)$$

and consequently the temperature of the water varies sinusoidally.

The back-and-forth movement required of the turning wheel on the variable transformer was generated mechanically in the manner shown schematically in Fig. 4. A rod was fastened to a motor-driven shaft, which made one revolution in time θ_0. At the free end of the rod was fastened one end of a wire which was allowed to slide through a ring situated at the periphery of the circle generated by the free end of the rod. The other end of the wire was wound around the turning wheel of the variable transformer. For a rod of length r, Fig. 4 shows that the distance g, and therefore the turning wheel position will vary as:

$$g = r\sqrt{2}\ \sqrt{1 - \cos 2\pi\,\theta/\theta_0}$$

and the voltage output from the transformer will vary as indicated by equation (7).

EXPERIMENTAL MATERIALS AND RESULTS

To date, the thermal conductivities of only two sample beds have been determined. Results for beds composed of sheets of glass fiber fabric were obtained at three mean temperatures and saturation degrees covering the whole interval between zero and unity. Physical data for the two beds are given in Table I.

Table I. Physical Data for Experimental Beds

	Bed A	*Bed B*
Thickness of one sheet, cm.	0.0156	0.0219
Void fraction	0.844	0.719
Bulk density, g./cc.	0.463	0.686
Solid density, g./cc.	2.97	2.44
Specific heat of solid, cal./g.	0.20	0.20

To calculate the effective thermal conductivity from the measured thermal diffusivity it is necessary to know the effective density, ρ_e, and effective specific heat, C_e. These values were obtained from equations (8) and (9):

$$\rho_e = (1 - \epsilon)\rho_s + \epsilon_w\rho_w + (\epsilon - \epsilon_w)\rho_a \qquad (8)$$

and

$$C_e\rho_e = (1 - \epsilon)\rho_s C_s + \epsilon_w\rho_w C_w + (\epsilon - \epsilon_w)\rho_a C_a \qquad (9)$$

Experimental results of the thermal conductivity of bed A and bed B are given in Figs. 7 and 8. The solid curves on these figures give the calculated values.

CORRELATION OF DATA

Many correlation equations which predict the thermal conductivity of two-phase systems containing a solid and gas or liquid phase have been developed. Jacob (*12*) has presented equations for the thermal conductivity of porous insulating materials, fine powders, and building materials. Deissler and Eian (*13*) give a semiempirical relationship for the thermal conductivity of packed beds with void fractions from 0.2 to 0.6. Schotte (*14*) has developed a correlation based on the Deissler-Eian relationship. His correlation predicts the thermal conductivity of packed beds for various conditions of pressure, temperature, and particle size. He states that radiant heat transfer becomes significant for large particles and at high temperatures. Many other studies (*6, 15, 16, 17, 21*) of the two-phase systems have been made with the same goals.

In a three-phase system such as prevails during a drying process, the problem becomes more complicated and data are more scarce. Bell (*18*) reports thermal conductivities at various moisture contents in a bed of layers of wool flannel. Although these data were obtained when the sample was being dried and are evaluated at the mean temperature of a wide range, they are similar to data presented here. Bell found that for an average material temperature of about 25°C. the thermal conductivity varies almost linearly with saturation degree, and that the thermal conductivity at full saturation is approximately a factor of ten greater than that of dry material.

Han and Ulmanen (*19*) report the thermal conductivity of paper at various moisture contents, but over a rather wide temperature range. Their data are obtained from measurements of the temperature history in a drying sheet of paper and they show that the thermal conductivity is very strongly dependent on the moisture content of the sheet.

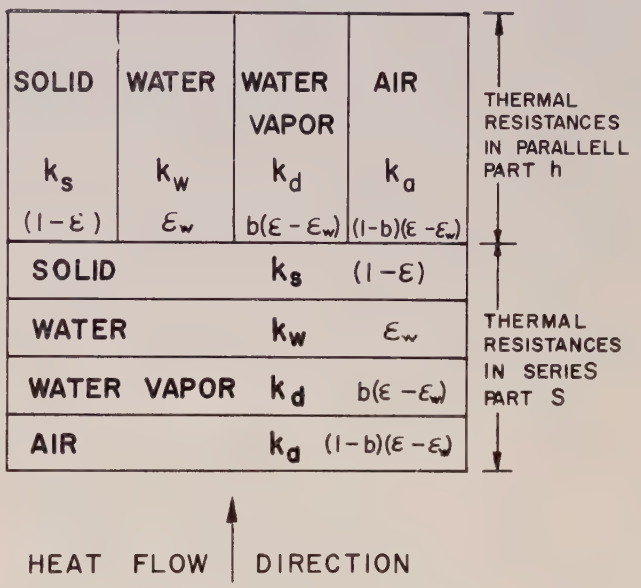

Fig. 5. Model for heat transfer in porous materials

Neither Bell nor Han and Ulmanen made any attempt to find a correlation equation which would fit their data.

Krischer and Esdorn (*1*) measured the thermal conductivity of porous bodies at several temperatures and moisture contents by an unsteady-state method. They also developed a theory (*20*) which predicts the thermal conductivity as a function of temperature and saturation degree. The correlation equation (*17*) is based upon their theory.

To derive a correlation equation for the thermal conductivity of three-phase porous materials the model shown in Fig. 5 was used. Basic to this model is the assumption that heat is transferred through a system of parallel and series resistances. The different modes of heat transfer considered in this model are:

1. Conduction of heat in the solid, water, and air, for which the conductivities are k_s, k_w, and k_a, respectively.
2. Heat transfer by an evaporation-diffusion-con-

densation process for which the conductivity is represented by k_d.

The thermal conductivity for diffusion, k_d, must be explained in some detail. Consider a pore with surface area A and length L in a temperature field with gradient dt/dL. If the walls of the pore are wetted, the air in the pore is saturated with water at its vapor pressure. Since the pore is in a temperature field, the partial pressure of water in the air space will have a gradient, and water vapor will diffuse through the pore. To keep the vapor at saturation pressure in all parts of the pore, vapor will condense in the "cold" portion of the pore, and liquid will evaporate in the "hot" portion. Thus, heat corresponding to the

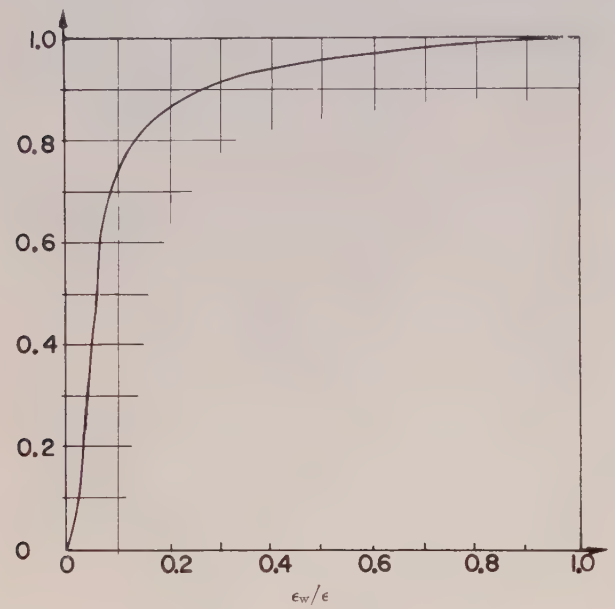

Fig. 6. The fraction of total available pores which contain water

latent heat of evaporation will be transferred through the pore in an evaporation-diffusion-condensation cycle.

The rate of diffusion through a pore can be calculated from the equation:

$$G = -A \frac{DM}{RT} \frac{p}{(p - p_s)} \frac{dp_s}{dL} \qquad (10)$$

where G is the rate of vapor transport, D the vapor diffusivity, p the total pressure, and p_s the partial pressure of the vapor. Also, since the air in the pore is saturated with water vapor:

$$\frac{dp_s}{dL} = \frac{dp_s}{dt} \frac{dt}{dL} \qquad (11)$$

The rate of heat transfer associated with this vapor transport is λG, where λ is the latent heat of evaporation. It follows that

$$Q = \lambda G = -A \frac{DM}{RT} \frac{p}{p - p_s} \frac{dp_s}{dt} \frac{dt}{dL} \qquad (12)$$

or

$$Q = -A\, k_d \frac{dt}{dL} \qquad (13)$$

where

$$k_d = \frac{DM}{RT} \frac{p}{p - p_s} \frac{dp_s}{dt} \lambda \qquad (14)$$

and dp_s/dt can be calculated from the vapor pressure curve.

Values of k_d were calculated from equation (14) for several temperatures. The results, given in Table II, show that k_d is highly temperature-dependent. The thermal conductivity of the solid, the air, and the water can be considered independent of temperature, compared with k_d. Since the thermal conductivity of moist solids has been observed to be temperature dependent, it follows that the thermal conductivity of moist porous materials at temperatures above room temperature is strongly dependent on the rate of heat transfer resulting from this evaporation-diffusion-condensation cycle.

Table II. Calculated Values of k_d

t, °C.	30	40	50	60	70	80	90
k_d, cal./cm. sec.°C.	0.488×10^{-3}	0.924	1.58	2.55	4.13	7.28	16.91

Heat transfer by vapor diffusion can occur only in a pore in which the walls are wetted. When the saturation degree approaches zero, some of the pores will not contain liquid. Therefore, heat transfer by vapor diffusion will not occur in the whole vapor volume $(\epsilon - \epsilon_w)$, but only in a fraction, b, of this volume. In the remainder of the vapor volume, $(1 - b)(\epsilon - \epsilon_w)$, heat will be transferred by conduction in the gas. Values of b at different saturation degrees have been taken from the literature (*20*) and are reproduced here in Fig. 6.

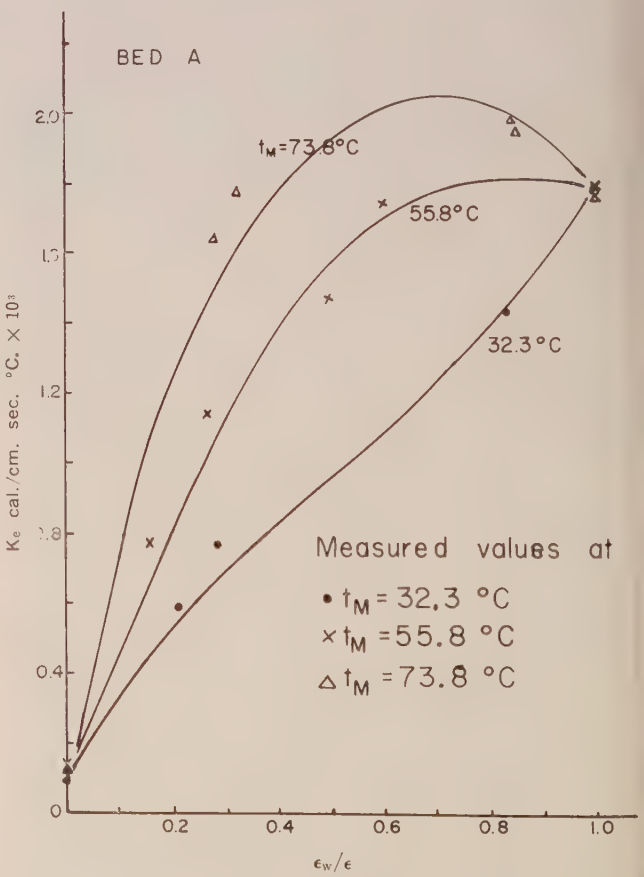

Fig. 7. Calculated and measured values of the thermal conductivity of bed A

The thermal conductivities of the parallel and series systems k_1 and k_2, respectively, have been determined from equations (15) and (16):

$$k_1 = (1 - \epsilon)k_s + \epsilon_w k_w + b(\epsilon - \epsilon_w)k_d + (1 - b)(\epsilon - \epsilon_w)k_a \quad (15)$$

and

$$\frac{1}{k_2} = \frac{(1 - \epsilon)}{k_s} + \frac{\epsilon_w}{k_w} + \frac{b(\epsilon - \epsilon_w)}{k_d} + \frac{(1 - b)(\epsilon - \epsilon_w)}{k_a} \quad (16)$$

The conductivities k_1 and k_2 were considered to be connected in series. This gives, for calculation of the effective thermal conductivity, k_e, of the total system:

$$\frac{1}{k_e} = \frac{h}{k_1} + \frac{s}{k_2} \quad (17)$$

where the parameters h and s are measures of the relative rates of heat transfer in the parallel and series systems. These parameters can be interpreted as descriptive of the geometry of the material.

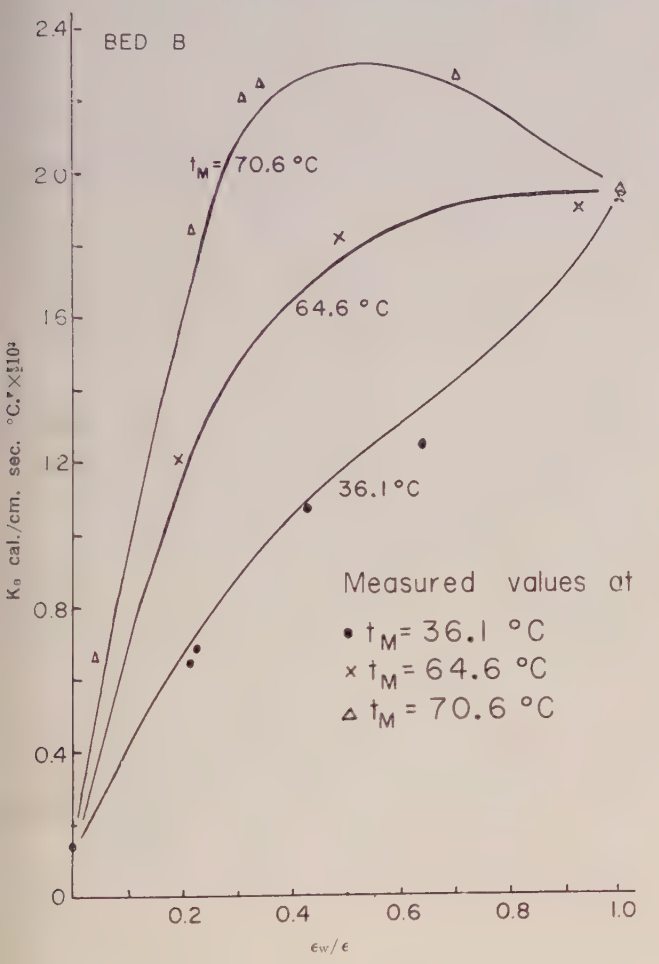

Fig. 8. Calculated and measured values of the thermal conductivity of bed B

Since values of h and s cannot be predicted accurately, they were determined empirically from experimental data for saturation degrees of zero and unity. At these points the system is reduced to a two-phase system, solid-gas or solid-liquid. With this method it is possible to predict the thermal conductivity of porous systems as a function of temperature and moisture content when the thermal conductivities of the completely dry and completely saturated material are known.

With $k_s = 2.2 \times 10^{-3}$, $k_w = 1.47 \times 10^{-3}$, and $k_a = 0.064 \times 10^{-3}$ cal./cm. sec. °C., the following values of h and s were obtained for the two beds:

	Bed A	*Bed B*
h	0.047	0.489
s	0.825	0.441

The solid curves in Figs. 7 and 8 give the effective thermal conductivities, k_e, calculated for the two experimental beds from equations (15) through (17) at the three experimental temperatures as functions of saturation degree.

CONCLUSIONS

1. The dynamic Angstrom method, in which the propagation velocity of a heat wave is measured, was used to determine the thermal conductivity of porous materials at various temperatures and moisture contents. The method permits reliable evaluation of the thermal conductivity at a mean temperature.
2. The data obtained were used to check a correlation equation. It is shown that the thermal conductivity at various temperatures and moisture contents can be calculated when the thermal conductivities of the material in the dry and fully saturated states are known.
3. The results show that in moist porous materials at temperatures above room temperature the heat flux is to a large extent due to an evaporation-condensation cycle.

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The Neutral Fatty Materials in Paper Birchwood, *Betula papyrifera* Marsh

M. A. BUCHANAN, S. L. BURSON, JR., and C. H. SPRINGER

The neutral fatty materials of paper birchwood were separated on silicic acid columns into glycerides, and esters of sterols and other higher alcohols. The results indicate that about 90% of the combined acids are present as triglycerides, and approximately 4% are present as esters of sterols. Linoleic acid is the major combined fatty acid, but it is accompanied by palmitic, stearic, oleic, linolenic, arachidic, behenic, lignoceric, and other acids. Further work is needed for characterization of the sterols and other higher alcohols. Squalene was isolated in a yield corresponding to 4% of the benzene extract. Both the glycerides and the other ester fractions caused self-sizing in absorbent papers on oven-aging. Tests with known materials indicated that linoleic acid, the higher saturated acids, and triglycerides are effective self-sizing agents in papers which are oven-aged.

THE SMALL amounts of fatty materials present in pulpwoods are important because they contribute to pitch and loss of absorbency problems and because they are a source of valuable by-products in the southern kraft industry. Recent studies have shown that several different acids occur in wood, and that these for the most part are present as esters of glycerol and other alcohols (*1, 2, 3*). The presence of several acids makes the possible number of individual esters quite large, and the nature of these esters in wood has received very little attention because of the difficulties involved in the analysis of such complex mixtures. However, recent developments have provided improved techniques for the study of fatty materials. Column chromatography has been used for the separation of different classes of fatty acid esters (*4, 5, 6*), and gas chromatography enables a rapid characterization of fatty acid mixtures.

The fatty fraction of wood normally contains some sterol which, for the most part, seems to be present in a combined form. The nature of the combined sterol has been determined in only a few instances. King and Jurd (*7*) isolated the palmitic acid ester of β-sitosterol from wood of the African species *Sarcocephalus diderrichii*, and Kohlbrenner and Schuerch (*8*) obtained the mixed phthalic acid ester of β-sitosterol and 2-octyl alcohol from Sitka sprucewood. Sterol glucosides have been reported in the European aspen *Populus tremula* (*9*), in *Aristotelia serrata* (*10*), and in insect-infested wood of *Acer negundo* (*11*).

β-Sitosterol and the corresponding dihydro compound β-sitostanol or stigmastanol are the chief sterols in many species of wood, but the major sterols in some species appear to be compounds of undetermined structure. From the European birch, *Betula verrucosa*, Kahila and Rinne (*12*) obtained a crystalline sterol melting between 146 and 147°C. and $[\alpha]_D^{20}$ +24° Later, Selleby (*3*) fractionated the sterols from the same species, and suggested that both β-sitosterol and stigmastanol were present.

The present study was undertaken in an effort to separate the glycerides from other esters, and to test for the possible presence of sterol esters. Paper birchwood was selected because it contains a relatively high proportion of fatty materials. Initially, several attempts were made to separate the benzene extract of birchwood on silicic acid columns eluted with petroleum ether–chloroform mixtures, and on alumina columns eluted with mixtures of petroleum ether and benzene. Some separations of glycerides and sterol esters were achieved, but the separations were not as complete as desired. Subsequently, better results were obtained by eluting silicic acid columns with hexane–benzene and hexane-ether mixtures.

PRELIMINARY SEPARATIONS

Since only small samples can be separated on the silicic acid columns, certain preliminary separations seemed desirable. A benzene extract prepared from birchwood (346 g. ovendry basis) was first treated with petroleum ether to remove some insoluble materials. Additional nonfatty material and the free acids were removed with alumina, and finally the neutral fats were separated into three fractions on the basis of solubility in acetone at low temperatures. The yields from these preliminary separations are given in Table I.

SILICIC ACID SEPARATIONS

Each of the three fractions from the acetone separations were fractionated further on silicic acid columns, and the yields are given in Table II. From the fraction soluble in acetone at −50°C., a 1-g. aliquot was separated on the column, but the results in Table II are calculated on the basis of the total fraction. The total material from the other two fractions was separated on the columns.

Qualitative tests indicated that the sterol esters were concentrated in fractions 5 and 6 from the columns. Since fractions from column separations often overlap somewhat, fractions 5 and 6 from the material soluble in acetone at −50°C. were combined, and were rechromatographed on a silicic acid column using hexane–ether mixtures as eluting solvents. Only the main fraction which corresponded to a total of 211 mg. was investigated further. Fraction 5 from the material soluble in acetone at −25°C. likewise was rechromatographed on a new silicic acid column. In this case, the main fraction which amounted to 370 mg. was subsequently saponified. These two main fractions are referred to as the sterol ester fractions.

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Table I. Yields from Preliminary Separations of Benzene Extract

Yields expressed in grams

Fraction	*Yield*
Petroleum ether insoluble	0.17
Acids and losses	1.06
Petroleum ether-soluble neutrals	4.75
Soluble in acetone at −50°C.	3.24
Soluble in acetone at −25°C.	1.05
Insoluble in acetone at −25°C.	0.37
Loss in acetone separations	0.09

SAPONIFICATION AND CHARACTERIZATION OF THE RESULTING ACIDS

Selected fractions from the silicic acid column separation were saponified, and the yields of acids, unsaponifiables, and glycerol were determined as indicated in Table III. The liberated acids were examined by paper chromatography, and, after conversion into methyl esters were estimated by gas chromatography. The estimated compositions of the acid fractions are given in Table IV. These results were calculated by the method of internal normalization, and thus in a strict sense represent the proportion of the acids detected rather than composition. However, the acid fractions were relatively pure, and thus the results are believed to be an approximation of actual composition. Results with known mixtures indicated that, under the conditions used, the response of the gas chromatograph was approximately proportional to the weight of the component for palmitate, stearate, arachidate, behenate, and oleate, but that the response per unit weight of linoleate and linolenate was appreciably less. Accordingly, in calculating the data in Table IV, the responses for linoleate and linolenate were multiplied by a factor of 1.3, but no factors were used for the other esters. Results with an impure sample of methyl lignocerate suggested that the response for this ester may have been low, but since a pure authentic sample was not available, no correction was attempted for this ester.

In addition to the acids listed in Table IV, small amounts of other acids were indicated by gas chromatography, but were not detected by paper chromatography. The tentative identification of these is based on retention times only, and thus is somewhat uncertain. All samples seemed to contain myristic acid

Table II. Separations on Silicic Acid Columns

Yields expressed in milligrams

Fraction	*Solvent*[a]	*Volume*[b]	*Soluble in acetone at −50°C.*	*Soluble in acetone at −25°C.*	*Insoluble in acetone at −25°C.*
1	A	8.4	445	11	15
2	A	1.7	6	2	1
3	B	3.3	3	3	1
4	B	1.7	6	7	0
5	C	3.3	39	449	10
6	C	1.7	257	63	0
7	C	1.7	322	108	155
8	C	1.7	614	99	17
9	C	1.7	379	50	39
10	C	1.7	214	25	31
11	C	1.7	104	19	21
12	C	1.7	52	9	10
13	C	1.7	29	12	5
14	C	5.0	29	8	4
15	C	1.7	10	28	1
16	D	5.0	393	17	17
Losses			341	138	47

[a] A = hexane-benzene 85:15 (v/v), B = hexane-ether 99:1, C = hexane-ether 95:5, D = ether-methanol 75:25.
[b] Volume of eluting solvent expressed as ml. per g. of silicic acid.

Table III. Saponification Data

Results expressed in milligrams

Fraction	*Soluble in acetone at −50°C.*	*Soluble in acetone at −25°C.*	*Insoluble in acetone at −25°C.*
Sterol ester fraction			
Unsaponifiables	130	238	...
Acids	95	143	...
Glycerol	0.2	0.0	...
Fraction 6			
Unsaponifiables	...	28	...
Acids	...	41	...
Glycerol	...	0.5	...
Fraction 7			
Unsaponifiables	34	...	...
Acids	280	...	...
Glycerol	30	...	...
Fraction 8			
Unsaponifiables	30	11[a]	98[a]
Acids	566	216[a]	72[a]
Glycerol	62	21.5[a]	0.6[a]
Fraction 9–11			
Unsaponifiables	66	14	4[b]
Acids	603	96	84[b]
Glycerol	72	8.4	6.8[b]
Fraction 12–15			
Unsaponifiables	36	...	...
Acids	84	...	...
Glycerol	8	...	...

[a] Data for fractions 7 and 8 combined.
[b] Data for fractions 9–12 combined.

Table IV. Composition of Acids as Estimated by Gas Chromatography

Results expressed as percentages

	Soluble in acetone at −50°C.	*Soluble in acetone at −25°C.*	*Insoluble in acetone at −25°C.*
Sterol ester fraction			
Palmitic	6	4	...
Stearic	5	28	...
Oleic	4	<1	...
Linoleic	82	61	...
Linolenic	2	...	...
Arachidic	...	1	...
Behenic	...	2	...
Fraction 6			
Palmitic	...	6	...
Stearic	...	35	...
Oleic	...	1	...
Linoleic	...	34	...
Arachidic	...	15	...
Behenic	...	4	...
Lignoceric	...	<1	...
Fraction 7			
Palmitic	16	...	...
Stearic	4	...	...
Oleic	6	...	...
Linoleic	67	...	...
Linolenic	2	...	...
Fraction 8			
Palmitic	4	7[a]	2[a]
Stearic	1	16[a]	10[a]
Oleic	2	2[a]	2[a]
Linoleic	90	55[a]	8[a]
Linolenic	1	1[a]	...
Arachidic	...	6[a]	30[a]
Behenic	...	7[a]	31[a]
Lignoceric	...	...	4[a]
Fractions 9–11			
Palmitic	2	9	14[b]
Stearic	1	9	8[b]
Oleic	<1	2	1[b]
Linoleic	86	64	52[b]
Linolenic	9	6	3[b]
Arachidic	...	5	4[b]
Behenic	...	1	9[b]
Lignoceric	...	...	3
Fractions 12–15			
Palmitic	3	...	...
Stearic	2	...	...
Oleic	1	...	...
Linoleic	76	...	...
Linolenic	16	...	...

[a] Data for fractions 7 and 8 combined.
[b] Data for fractions 9–12 combined.

Table V. Self-Sizing Tests
Results expressed as fluorescent size test in seconds

	Concn. of solution, mg./ml. 16	4
Linoleic acid	10	2
Linolenic acid	4	None
Arachidic acid	30	None
Behenic acid	31	28
Tall oil rosin	17	None
Tristearin	28	26
β-Sitosterol	4	2

and a C_{17} saturated acid, and samples containing the higher acids apparently contained a C_{23} acid. Most samples gave a peak corresponding to the ester of palmitoleic acid.

Unsaponifiable Fractions

The unsaponifiables from the two main sterol ester fractions were analyzed for sterol content by precipitation with digitonin (*13*). The results indicated 38.4% sterol in the unsaponifiables from the sterol ester fraction of the material soluble in acetone at −50°C., and 34.4% in the corresponding fraction of the material soluble in acetone at −25°C.

In an attempt to characterize the paper birch sterol, appropriate fractions from several different separations were crystallized from 95% ethanol. Usually the melting points for the initial crystallizations were in the range of 140 to 142°C., but in one instance the melting point was 145°C. Different lots of the crystals were combined, and were recrystallized to give a product with a melting point between 142 and 144°C. and $[\alpha]_D^{23}$ −12° (chloroform). The melting point is higher than that of β-sitosterol, and the negative rotation suggests that the crystals are not stigmastanol. Probably they are a mixture of sterols, but further studies are needed to establish their nature.

The unsaponifiable fractions also were examined by paper chromatography using oil-treated paper developed with acetic acid–water 80 : 20 or 95 : 5. Exposure of the chromatograms to iodine vapor followed by inspection under ultraviolet light indicated that all of the fractions contained a number of unsaturated compounds. None of these was isolated or identified. The unsaponifiables from fractions 7 and 8 from the material insoluble in acetone at −25°C. was an oil, and on chromatographing gave four major and five minor spots ranging from R_f 0.0 to 0.8. The spacing of these spots suggested that they might be due to members of a homologous series. Accordingly, the infrared spectrum was determined. In addition to hydroxyl bands at 3.03 and 10.02 μ indicative of hydroxyl groups, major bands were present at 3.45, 6.92, and 7.26 μ characteristic of carbon-hydrogen bonds, and at 5.99 and 12.0 μ due to aliphatic unsaturation. Except for the hydroxyl bands, the major bands were very similar to those present in the spectrum of squalene.

SQUALENE

Hydrocarbon fractions eluted from alumina columns with petroleum ether in the preliminary work were colorless viscous oils which on standing changed to a glasslike material insoluble in petroleum ether. The infrared spectrum of the original fraction proved to be identical to that of known squalene, and the addition of hydrogen chloride gave squalene hexahydrochloride. The yield of hexachloride indicated that the original wood contained 0.07% squalene, and that the squalene content of the benzene extract was 4%.

Squalene is a dihydrotriterpene, and has been found in many oils of vegetable and animal origin. A material resembling squalene has been isolated from pine bark (*14*), and analysis of tall oil has indicated 0.1% squalene (*15*).

SELF-SIZING

Absorbent papers often become water resistant during normal storage or on artificial aging. This loss of absorbency or self-sizing is due to the extractives remaining in the pulp (*16*). The neutral part of the benzene extract of birch and other woods contains materials which are especially efficient in causing the loss of absorbency. Some of the fractions from the column separations were tested for self-sizing ability by adding 50-λ portions (λ = 0.05 ml.) of benzene solutions containing 1 mg. of sample per ml. to handsheets prepared from alcohol-benzene extracted semichemical pulp. After oven-aging at 100°C. for 15 hr., sizing was estimated by floating the sheet on water. These tests showed that both the sterol ester and the glyceride fractions caused self-sizing.

Similar tests were made on a series of known substances. For these, Whatman no. 1 filter paper was used as the test paper. Because of the greater porosity of the filter paper, a higher concentration of the treating solution was required for the development of self sizing. After oven-aging for 15 hr. at 100°C., the papers were conditioned at 50% R.H., and fluorescent size values were determined for the treated spots. Because of the small area of the spots, the end point was determined visually. Results with materials which produced self sizing are given in Table V. Under the same conditions, no sizing was developed by treatment with myristic, palmitic, stearic, and oleic acids, or with the methyl esters of palmitic, stearic, oleic, linoleic, and linolenic acids. Each treated area corresponded to approximately 65 mg. of paper. Thus, treatment with the 4 mg. per ml. solutions involved the addition of about 0.3% of test substance.

The results with the known materials indicate that for oven-aging, the high-molecular-weight fatty materials are more effective in producing self-sizing than are the substances of lower molecular weight, and that linoleic acid is more effective than are the corresponding saturated and mono-unsaturated acids, stearic and oleic acids. Triglycerides seem to be especially effective. Known esters of sterols or triglycerides containing linoleic acid were not available for testing, but it seems likely that these would be highly effective under the test conditions.

In the natural aging during normal storage of absorbent papers, temperatures are considerably less than 100°C. and, in addition, a redistribution of extractives from ray cells to the fibers probably is necessary for development of self-sizing. Consequently, the lower molecular weight fatty materials may be more important in the usual problem involving loss of absorbency. Since linoleic acid is the major fatty acid in aspen and birch and is one of the chief acids in pine, it seems likely that it and its esters are important in the loss of absorbency in absorbent papers.

EXPERIMENTAL

A typical paper birch tree was felled on June 29, 1960, and a section of the main stem with a diameter of 6 in. and 35 annual rings was converted into sawdust. After storage in a freezer for 4 weeks, a 574-g. portion of the green sawdust (346 g. ovendry basis) was extracted with benzene in a Soxhlet for 6 hr. The solvent was removed under reduced pressure, and the extract was mixed with petroleum ether (b.p. 30–60°C.). The petroleum ether solution was filtered from some insoluble material, and then was mixed with 60 g. alumina (Fischer Scientific Co., Cat. No. A-540). The slurry was transferred to a column, and the neutrals were eluted with chloroform.

The neutrals soluble in petroleum ether were dissolved in 120 ml. of acetone and 5 g. of Analytical Grade Celite was added. After cooling to −50°C. the soluble fraction was removed through a fritted disk immersion filter. The insoluble fraction was crystallized two additional times from 120-ml. portions of acetone in a similar manner. The three filtrates were combined, and the solvent removed to give the fraction soluble in acetone at −50°C. The insoluble fraction was then crystallized three times from 40-ml. portions of acetone at −25°C. The final insoluble material was separated from the Celite by dissolving in acetone at room temperature, while the filtrates from the crystallizations at −25°C. were combined to yield the fraction soluble in acetone at −25°C.

Silicic Acid Separations

The fines were removed from silicic acid (Mallinckrodt No. 2847) by suspending 200 g. in 2 liters of methanol, and then decanting the supernatant liquor after 30 min. This treatment was repeated once, and the settled fraction air-dried. It was then mixed with 0.5 part Hyflo Supercel,[a] and the mixture was heated for 15 hr. at 105°C. A quantity of the silicic acid-Hyflo Supercel corresponding to 90 g. per 0.1 g. of fatty material was suspended in chloroform. The suspension was transferred to a column of such a size that the final packed height was about 12 to 15 cm. The chloroform was replaced by washing with hexane, and then the sample was transferred to the column with hexane. Fractions were eluted with the solvents indicated in Table II. The hexane was a technical grade (Phillips Petroleum Co.) which had been redistilled from potassium permanganate. Reagent-grade benzene and absolute ether were used as purchased.

Saponification and Analysis of the Products

Fractions from the silicic acid columns were saponified by refluxing for 2 hr. with alcoholic potash (33 g.p.l. KOH in absolute ethanol)-benzene 5:1. The reaction mixture was diluted with water and the ethanol was removed by heating on a steam bath. Dilute sulfuric acid then was added until the mixture was acid to Congo red, and then the acids and unsaponifiables were extracted with U. S. P. ether. The aqueous layer was analyzed for glycerol by the chromotropic acid procedure described by Smullin, *et al.* (*17*). The ether solution was extracted with 1% NaOH to separate the free acids from the unsaponifiables. The sterol contents of two unsaponifiable fractions were determined by precipitation with digitonin (*13*).

For analysis by gas chromatography, the acid fractions were converted into the methyl esters with diazomethane (*18*), and the esters were separated on a 5-ft. column of diethylene glycol succinate (20% packed on Chromosorb-W)[a]. Column temperatures were in the range of 185 to 190°C., corrected flow rates were 71 ml. per min., and the instrument was an Aerograph Model A-110-C[b] with a disk integrator.

Squalene Hexahydrochloride

Both known squalene and the hydrocarbon oil obtained from an alumina column by elution with petroleum ether were treated as follows: the oil (0.5 g.) was dissolved in 3 ml. of acetone, and the solution was cooled in a mixture of ice and salt. Dry hydrogen chloride was passed into the cooled solution for 5 min. The solution then was removed from the ice, 10 ml. of absolute ether was added, and the addition of hydrogen chloride was continued at room temperature for 40 min. During this time most of the ether evaporated, and the product started to crystallize. The material was crystallized from acetone until a constant melting point of 111 to 112°C. was reached. There was no depression when the crystals were mixed with the hexahydrochloride prepared from known squalene. Some isomerization occurs during the formation of squalene hexahydrochloride, and thus the melting point of the product depends on the reaction and crystallization conditions (*19*).

SUMMARY AND CONCLUSIONS

Although individual esters were not isolated, the present data support the concept that the neutral fatty materials in birchwood are comprised chiefly of triglycerides, and that small amounts of sterol esters and esters of other higher alcohols are present. There was no evidence of any mono- or diglycerides.

One-fourth of the material isolated from the silicic acid columns was not investigated further, but most of this was in fractions 1 and 16, which were believed to be free of fatty acid esters. On the basis of the materials actually studied, approximately 90% of the fatty acids were present as triglycerides, while about 4% appeared to be present as sterol ester. The total glycerol determined amounted to 200 mg. This corresponds to approximately 1.8 g. of triglycerides or 0.5% of the original wood. The total sterol estimated amounted to 132 mg., which corresponds to 0.22 g. of sterol esters assuming an average molecular weight of the acid equal to that of linoleic acid. This is 0.06% on the basis of the wood.

The total acids liberated by saponification were comprised of about 75% linoleic acid, 2 to 6% each of palmitic, steric, oleic, linolenic, arachidic, and behenic acids, and less than 1% lignoceric acid. Small amounts of other acids were also present and these seemed to include myristic, and C_{17} and C_{23} saturated acids.

Approximately 80% of the glycerol determined was obtained from fractions 7 to 11 from the materials soluble in acetone at −50°C. For these fractions the ratio of glycerol to acids was approximately 0.11, suggesting that esters other than triglycerides were essentially absent in these fractions. Although small amounts of unsaponifiables were obtained from these, it

[a] Johns-Manville Co., Manville, N. J.
[b] Wilkins Instrument and Research, Walnut Creek, Calif.

seems likely that the unsaponifiables were present initially as nonesterified materials. Another 10% of the glycerol determined was from fractions 7 and 8 of the material soluble in acetone at −25°C. For these fractions, the ratio of glycerol to acids suggests that about 10% of the acids were present as nonglycerides. For the remaining glycerol-containing fractions, the low ratios of glycerol to acids indicate that even more of the acids were present as esters other than glycerides.

The sterol esters were concentrated in fractions from the materials soluble in acetone at −25 and −50°C., with the greater proportion being in the former material.

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Glycerol was determined by Mrs. T. L. Scroggins, infrared spectra were determined and interpreted by L. O. Sell, and fluorescent size values were determined by J. Mollen.

The Delamination Resistance of Polymer-Impregnated Papers

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A detailed study of the various factors affecting the peel-type delamination strength of untreated and polymer-treated papers has been made. This property shows a maximum at between 35 and 50% R.H.; it is independent of straining rates at high rates but drops off considerably at very slow rates. This latter effect is attributed to viscous flow and viscoelastic deformations. The effect of different types of polymers on the delamination strength varies; hard, nonfilm-forming and soft-flowing polymers bring about only minor improvements; whereas tough, rubbery polymers impart excellent strength to papers. Polyvinyl acetate also confers excellent delamination-resistant properties to paper, and the possible reasons for its good performance are discussed. The medium from which the polymer is applied is important, latices and benzene solutions being superior to water-containing solvent systems. Finally, the effect of the degree of orientation in the paper was studied and it is shown that considerable improvements in the delamination strength can be brought about by increasing the amount of Z-oriented fibers.

The *Z*-directional strength properties of paper and paperboard are of great importance for a number of applications, and have recently created considerable interest. To determine this type of strength, the force is applied perpendicular to the plane of the paper, the plane of rupture coinciding with that of the paper sample. Depending on the fashion by which the force is applied to the sample, two classes of *Z*-directional or delamination strength measurements can be differentiated. In the "peel-type" delamination-resistance measurements, dealt with in this paper, the force required to delaminate a paper strip of standard width is determined. The delamination is in this case a gradual process in contrast to the "tensile-type" delamination-strength measurements in which the force is applied not to the ends of a paper strip, but to the whole area of the sample at once. It is important to realize that properties measured by the two methods are different and while the tensile-type delamination tests may yield a measure of the internal bonding as has been claimed, the fiber-to-fiber bonding alone certainly does not determine the delamination strength measured by the peel-type tests.

Because of the importance of *Z*-directional strength properties, an extensive study on various testing methods was recently started by TAPPI (*1*). The tensile-type tests utilize either common tensile testers (*2*) or a Jumbo Mullen tester (*3*). The peel-type tests were first introduced for testing paperboard (*4*) and multiply papers (*5*). For the purpose of testing papers for the pressure sensitive tape manufacture, a special peel-type test was developed by the Permacel Division of the Johnson & Johnson Co., New Brunswick, N. J. (*6*). This method is applicable to both ordinary papers and paper-polymer combinations. The principle of the test is to heat-seal a tape with a standard cloth backing on both sides of the paper specimen, and to measure the force required to pull the ends of the cloth tapes in opposite directions, preferably with a constant-strain rate-tensile tester fitted with a recording instrument such as the Instron. An average of the recorded force values is taken as the delamination strength of the paper. The reproducibility of the test is generally excellent, the standard deviation being less than 2% of the measured strength. However, the nature of this method obviously limits its application to cases where the de-

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lamination resistance is less than the strength of bonding between the paper sample and the cloth tape. It is also important that the cloth tape be highly standardized, since its stiffness will affect the results.

EXPERIMENTAL

Measurement of Delamination Resistance. The procedure was essentially identical with the method described by Dunlap (*6*). Both the paper sample and the commercial cloth tape with thermoplastic adhesive surface were cut into strips 8 in. long and 1 in. wide. The paper was invariable cut in the machine direction. The paper strips were placed between two pieces of tape and pressed together as a sandwich on a hot plate using a pressure of 2.6 p.s.i. at a temperature of 155°C. for 30 sec. (15 sec. on each side). The bonded sandwich was then cut to a width of 0.59 in. and conditioned in constant humidity room for at least 24 hr.

The measurement was carried out with an Instron tester, model TT-D (Instron Engineering Co., Canton, Mass.) One end of the specimen was first split apart by hand and the ends of the tape were then attached to the jaws of the instrument. The applied crosshead speed was 2 in. per min., unless otherwise noted in the data. The force required to continue the splitting was automatically recorded on graph paper. From the saw-tooth curve thus obtained equal numbers (10) of representative maxima and minima were selected. The average force from these measurements was converted to a sample width of 1 in., giving the delamination resistance in lb. per in. Three or four tests were conducted for each set of conditions. The results were found to be reproducible within 2%, even if the strip width was varied.

Determination of Z-Orientation. The x-ray method of determining the *Z*-directional orientation of fibers in paper recently described by Hermans and Aaltio (*7*) was used. A recording Geiger counter goniometer was used to scan the (002) diffraction maximum. Since the presence of saturant in the paper displaces the Geiger counter curves to a higher level, the half-maximum angle rather than $F_{max.}/F_{min.}$-ratio was used to estimate the *Z*-directional orientation.

Materials. Commercial machine-made papers for impregnation, kindly provided by the Permacel Division of Johnson & Johnson Co., were used throughout the experiments. These papers were made from bleached alpha-pulp, and the average basis weight was 52 g.s.m. and the caliper 4.3×10^{-3} in.

The following commercial polymer preparations were used for the impregnation experiments: GRS rubber latex Naugatex 2001* with 43.4% solids, polyvinyl acetate latex Emulsion C† with 42.8% solids, solid polyvinyl acetate,‡ average molecular weight approximately 140,000. Three styrene-2-hexylacrylate copolymer latices with the following styrene/2-hexylacrylate ratios (on weight basis): 3:2, 3:1, and 1:3. were prepared in our laboratories.

Impregnation and Conditioning. Strips of paper (8 by 1 in.) were immersed in the saturant latex or solution for a period of 30 min. The solids content of the saturating bath was previously adjusted according to the desired retention. After the impregnation was complete, the excess saturant was removed by pulling the strips through a narrow slit between two parallel round glass rods. The strips were then air-dried by hanging them on clips at room temperature. No difference in polymer content was found between the two ends of the sample. The curing of the strips was carried out by heating them at 115°C. for 2 min., after which they were conditioned in a constant humidity room. The resin retention was determined by weighing a conditioned strip before and after impregnation.

In order to study the effect of relative humidity on delamination resistance, it was necessary to condition the strips sandwiched between the cloth tapes to various degrees of relative humidity. The conditioning was carried out in closed desiccators, using the various salt solutions and distilled water to produce the desired humidities, according to the TAPPI Standard Method T 447 m-53. Thirteen days' conditioning was found sufficient to reach the equilibrium in most cases. However, the latex-saturated papers at high humidities required 20 to 30 days for the attainment of moisture equilibrium.

RESULTS AND DISCUSSION

The Nature of Delamination Resistance. The process of delamination consists essentially of creating two new surfaces on both sides of the plane of rupture. Accordingly, the delamination strength, in the formal sense, is similar to surface tension and has a dimension analogous to it (lb. per in.). Because the fibers in paper are essentially plane-oriented, the new surfaces are formed mainly through the breakage of the interfiber bonds. In cases where single fibers cross the plane of rupture, new surfaces may be formed also by the breakage of fibers themselves.

It seems reasonable to assume that the splitting of the paper occurs essentially along a path which is determined by the weakest area in the paper structure. Consequently, the new area exposed, as well as the amount of surface work done in the delamination process, should not depend on the rate at which the process is carried out.

Experimental results on untreated paper (Fig. 1) as well as on latex-saturated papers (Fig. 2) demonstrate that although the measured force remains essentially constant in the speed range from 2 to 20 in. per min. substantially smaller strengths are observed at lower rates. By extrapolating the delamination strength to zero rate, a value is obtained which, in the case of the unsaturated paper, amounts to about 75% of the maximum strength. In saturated papers, the extrapolated strength amounts only to 25 to 30% of the maximum value. It seems obvious that the rate-dependent differences between the extrapolated and maximum force values is not connected with surface work, but rather with viscoelastic deformations in the paper or paper-polymer system. Consequently, the strength of fiber-to-fiber or fiber-to-polymer bonding is one, but often not, the most important factor in determining the delamination resistance. Particularly in saturated papers, the deformational processes that extend from the area of rupture deep into the polymer-paper matrix

* Naugatuck Chemical Co., Naugatuck, Conn.
† National Starch Products, Inc., Plainfield, N. J.
‡ Union Carbide Plastics Co., Div. of Union Carbide Corp., New York, N. Y.

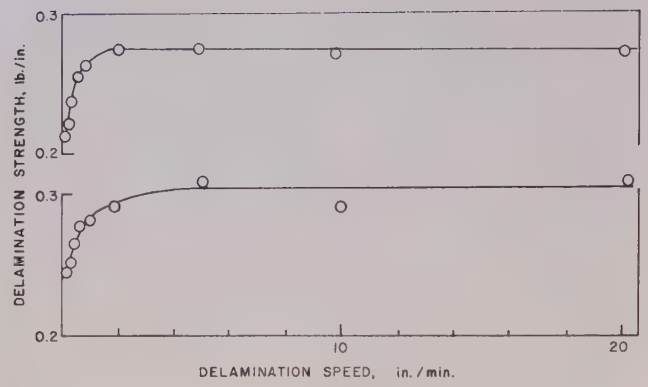

Fig. 1. Delamination strength as a function of straining rate. Typical curves for two base papers

consume the largest amount of energy expanded in the process.

Factors Affecting the Delamination Resistance. No detailed account of the relationship between the polymer properties and the delamination resistance of saturated papers has been reported. Rubberlike polymers, such as GRS or Nitrile rubbers are generally preferred for the saturation. Small amounts of phenolic resins added to the rubber have been found to enhance the delamination resistance (*6*). The latter effect may well be due to increased toughness of the polymer rather than the improvement of the polymer-fiber bond, as assumed earlier.

Figure 3 illustrates the effect of a number of different polymers on the delamination strength of paper. The tough rubbery polymers such as GRS and the 60-40 styrene-acrylate copolymers give excellent strength in line with previous comments. The short heat cure used, probably helps greatly in developing toughness in GRS rubber, a property which is intrinsic to the acrylate-styrene copolymer.

The high glass temperatures of the polystyrene and the 25-75 acrylate-styrene copolymer lead to poor film-forming properties of the corresponding latices, and very little strength is developed even after the heat cure treatment of 2 min. at 115°C. (*8*). On

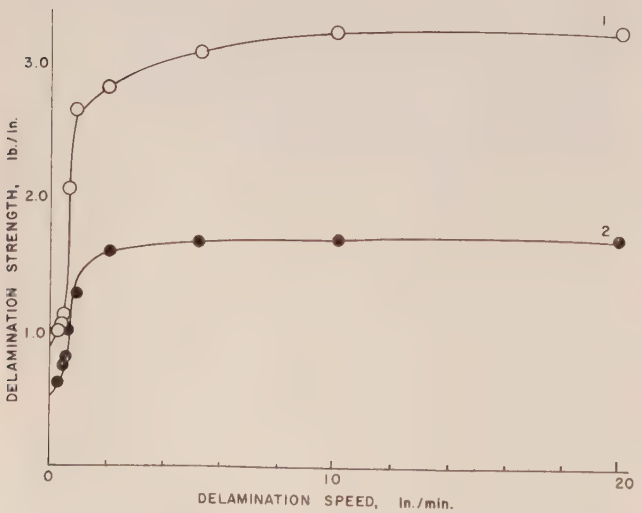

Fig. 2. Delamination strength as a function of straining rate

Curve 1: machine-impregnated polyvinyl acetate paper (51% of PVA of the weight of unsaturated paper). Curve 2: paper impregnated with GRS-latex (retention 60%).

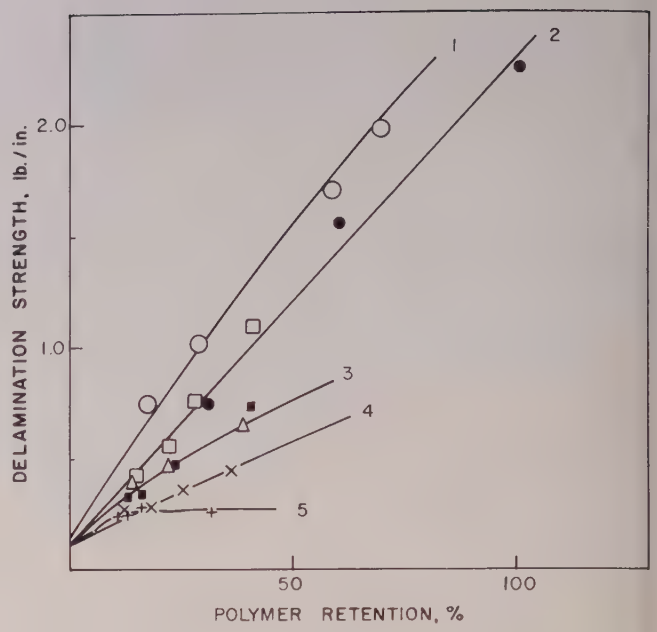

Fig. 3. Delamination strength of latex-impregnated papers as a function of polymer retention

Curve 1: polyvinyl acetate. Curve 2: ● GRS-rubber, □ styrene–2-hexylacrylate copolymer with 60% styrene. Curve 3: styrene–2-hexylacrylate copolymers, Δ 75% styrene, ■ 25% styrene. Curve 4: poly(2-hexylacrylate). Curve 5: polystyrene.

the other hand, polymers which have high viscous flow characteristics, such as the polyacrylate and the 75-25 acrylate-styrene copolymer, also can provide only limited reinforcing action. The excellent delamination strength imparted by polyvinyl acetate is paralleled by the tensile strength and elastic characteristics of papers treated with this polymer (*8*, *9*). It is thought that this strong, rigid film-forming polymer holds the bonds of the papers in place, with the polymer absorbing some of the increased stress per unit of

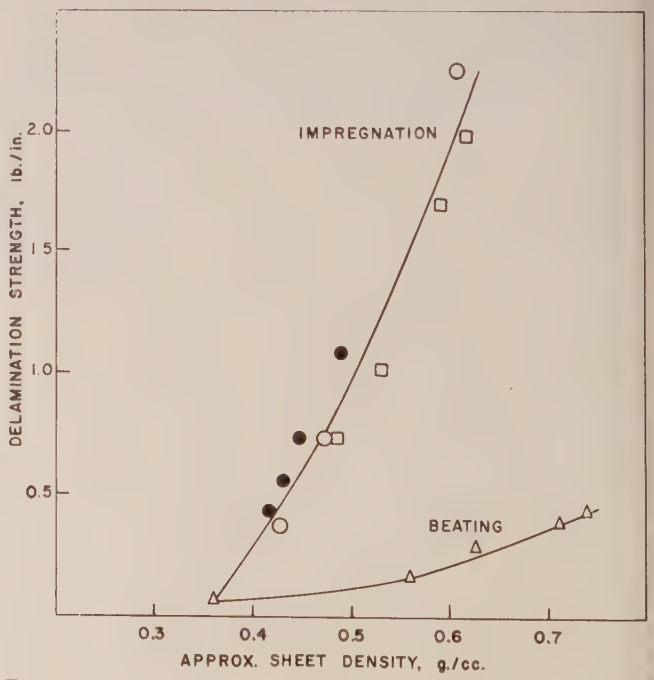

Fig. 4. The effects of polymer impregnation and beating on the delamination strength

Impregnants: ○ GRS-rubber, ● styrene–2-hexylacrylate copolymer with 60% styrene, □ polyvinyl acetate.

Table I. The Effect of Pretreatment with Cationic Starch on the Delamination Strength of Hycar-Impregnated Paper

Concn. of starch in satd. bath, %	Properties of pretreated paper: Density, g./cc.	Properties of pretreated paper: Delamination strength, lb./in.	Concn. of Hycar in satd. bath, %	Hycar-saturated paper: Total weight increase, %	Hycar-saturated paper: De lamination strength lb./in.
0.00	0.417	0.173	12.0	47.3	1.33
0.50	0.418	0.374	9.0	45.0	1.42
0.75	0.428	0.424	7.5	42.5	1.49
1.00	0.432	0.577	5.8	41.0	1.78

elongation (*8*); at very slow rates of straining polyvinyl acetate loses a good deal of its power to confer high delamination strength, as shown in Fig. 2, and as would be expected from its creep properties. The water sensitivity and stiffness of polyvinyl acetate-treated papers have apparently prevented their widespread use as paper backings.

The paper used for saturation acts as a matrix for the polymer. To ensure proper penetration and high retention of the latex, porous papers, usually made of high-alpha kraft pulps, are generally preferred. The uppermost limit of delamination resistance for a given paper is reached when all the voids in the paper have been filled by the polymer.

It is of interest to compare the effect of latex saturation, which consists essentially of filling the voids in paper with an extensible polymer, to that of beating where the voids are gradually reduced by increasing the number of direct contacts between the fibers. Figure 4 illustrates this comparison. In order to bring the results on a roughly comparable basis, the delamination strengths are plotted against sheet densities. The increase in interfiber bonding by the beating process which markedly improves the tensile properties, causes only a minor improvement in the delamination strength, whereas an increase by a factor of ten or more can be easily achieved by polymer saturation. It appears conceivable that the rigid structure of the beaten sheet inhibits the consumption of energy by deformational processes, referred to earlier in this paper. At low levels of polymer retention paper made of beaten pulps, or mixtures of beaten and unbeaten pulps, possess high delamination strengths than unbeaten sheets (curve 3, Fig. 8). Because of the high density of these papers, however, the penetration of the polymer is retarded and the retention is restricted to relatively low levels. An effect similar to that of beating, as far as the delamination resistance of the unsaturated paper is concerned, can be achieved by impregnating the paper with cationic starch. This recently introduced additive has excellent retention properties and undesirable increases in paper density or wettability are practically absent (Table I). Consequently, the saturation of the paper with latex is not impaired, and increased delamination values are obtained, even if the bath concentration is substantially reduced.

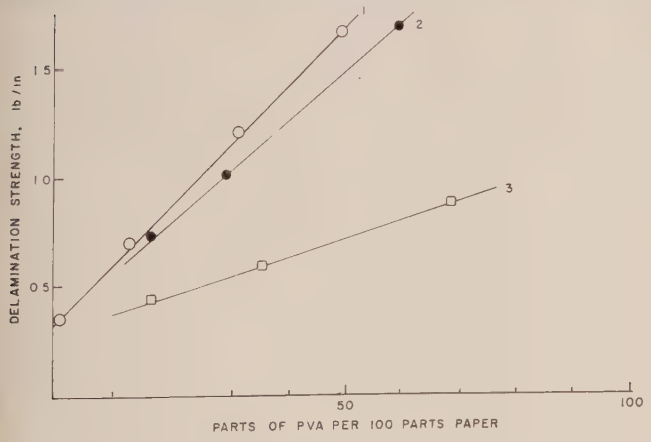

Fig. 5. Effect of impregnation medium on the delamination strength

Papers saturated with polyvinyl acetate using a solution in benzene (Curve 1), an aqueous latex (Curve 2), and a solution in a 3:1 methanol-water mixture.

Effect of Saturating Medium. The delamination strength is not determined only by the kind and amount of polymer added to the sheet; but can be varied by varying the vehicle in which the polymer is introduced to the paper. Figure 5 demonstrates how the delamination strength of a paper saturated with polyvinyl acetate is affected by the impregnation medium. While saturations using either an aqueous latex or a benzene solution of the resin impart similar delamination strengths to the paper, impregnation in a methanol-water medium provides substantially smaller strength properties at identical retention levels.

A part of the observed effect may be due to varying densities of the sheets. At a constant retention level, paper saturated from benzene solution has the highest

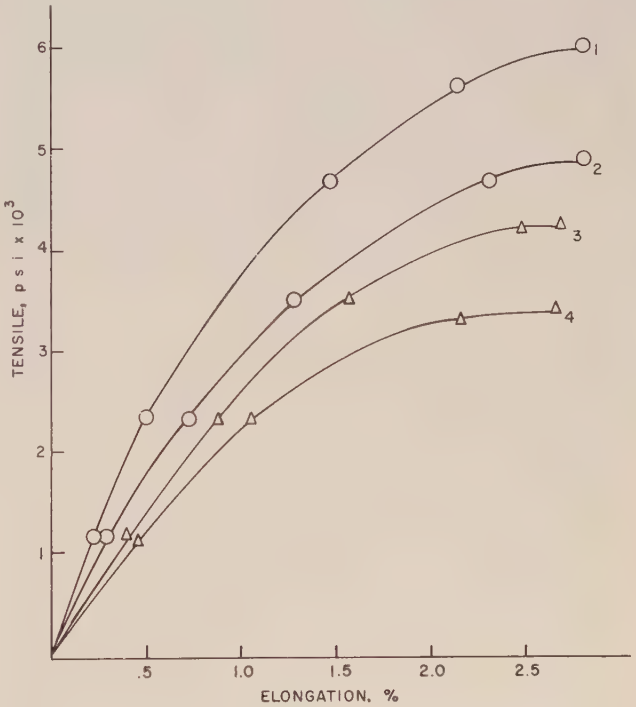

Fig. 6. Effect of impregnation medium on the stress-strain behavior of papers saturated with polyvinyl acetate

Curve 1: 18.5% retention from benzene solution. Curve 2: 7.6% retention from benzene solution. Curve 3: 19.9% retention from 3:1 methanol-water mixture. Curve 4: 7.0% retention from 3:1 methanol-water mixture.

density, whereas that impregnated with the resin solution in methanol-water has the lowest. Still, at a given sheet density, the methanol-water–treated paper has the lowest delamination strength value. Consequently, the way in which the polymer is distributed in the fiber matrix appears to have importance and is adversely affected by the use of highly polar hydrogen-bonding solvents as saturation media. The effect is not limited to delamination properties, but is also reflected in reduced modulus and tensile strength of the impregnated sheets, as shown in Fig. 6.

One possible explanation is that in the case of benzene the normal fiber-to-fiber bonds remain intact. In the case of the latex the bonds separate in the aqueous system, but the latex particles are too large (about 1000 A. diam.) to penetrate and interfere greatly with their reforming as the sheet dries again. However, with the methanol-water solutions some of the bonds separate and the polyvinyl acetate molecules can easily penetrate and be deposited or adsorbed onto the bonding surfaces, interfering with the strong fiber-to-fiber bonds and diminishing the overall strength of the sheet.

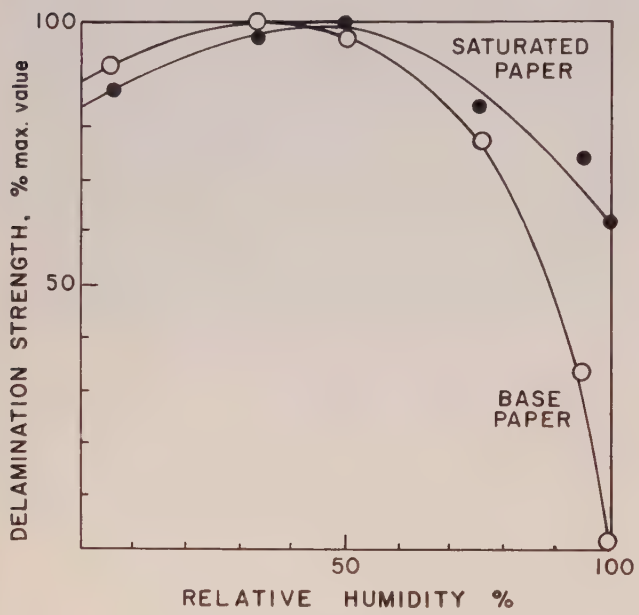

Fig. 7. Effect of relative humidity on delamination strength

The Effect of Relative Humidity. Both unsaturated and impregnated papers display a maximum in the delamination strength in the range from 35 to 50% R.H., as shown in Fig. 7. The somewhat decreased strength at lower relative humidities is probably due to the rigidity introduced to the paper matrix by too thorough drying, and is frequently observed with both tensile and bursting strength of papers. The stress–strain curves (*10*) also demonstrate a substantial change to a more rigid paper structure when the relative humidity is decreased from 65 to 5%.

At 100% R.H., the unsaturated papers have lost practically all of their strength, while impregnated papers, due to the wet-strengthening effect of the polymer saturation retain about 60% of their maximum delamination strength; in this connection, it is of interest to note the use of rubber latices for producing wet-strength papers (*11*). The preservation of both tensile and delamination strengths at high relative humidities is undoubtedly due to the same specific effects of the rubber impregnant.

The Effect of Fiber Orientation in Paper. In ordinary pulps, the tracheid fibers are almost straight and tend to assume, in the sheet-making process, a direction closely parallel to the plane of the paper, resulting in a layerlike structure. This arrangement is probably not ideal for good delamination strength. It would seem that a paper with a relatively large number of fibers (or fiber segements) in a tilted position to the plane of paper would resist the delamination process in a more efficient way. In particular, fibers with both ends on opposite surfaces of the paper may be expected to exert a pronounced reinforcing action. The extraordinarily high delamination strength, observed by Dunlap (*6*) for sheets made in butanol suspension and subsequently saturated with latex, may conceivably be due to this kind of effect.

Table II. Effect of Increased *Z*-Orientation on the Delamination Strength of Paper Saturated with 77.5 ± 2.6% of GRS-Rubber

Type of pulp	*Compression, %*	*Half-maximum angle, degrees, (002) diffraction*	*Delamination strength, lb./in.*
Untreated fibers	0.0	42.2	1.92
Untreated fibers	8.3	55.6	3.10
Modified fibers	0.0	51.0	2.63
Modified fibers	10.5	58.6	3.20

A method to determine the *Z*-orientation from x-ray diffraction data for sheets made of the same pulp was recently developed by Hermans and Aaltio (*7*). Since the *Z*-orientation is deduced from the orientation of crystalline cellulose, any process that is likely to modify the fibril orientation with respect to the fiber axis, such as flattening of the fibers through beating or high wet pressures, should be avoided if comparable data are to be obtained. On the other hand, the presence of non-oriented or randomly oriented fillers, or polymer impregnants, should not be harmful as long as the half-maximum angle in the (002) diffraction is used as a measure, since the effect of these additives is limited to shifting the experimental curve slightly upwards.

In principle, two methods are available for modifying the fiber orientation in paper. Firstly, the fibers themselves, prior to making the sheet, can be subjected to a special treatment in suspension to increase the number of bends in the tracheid fibers. Secondly, fibers in the paper web can be disoriented by compressing the sheet in one direction.

Methods of this sort have been investigated in the laboratories of the Permacel Division of Johnson and Johnson Co. At the authors' request, a series of such sheets were prepared by their laboratory. Special care was taken to ensure identical basis weight for the samples. The delamination strengths and *Z*-orientation of these sheets were measured both before and after saturation with a constant amount of latex (Table II).

The results obtained leave no doubt as to the importance of Z-directional orientation for high delamination strength. It seems likely that an increase in the number of Z-directional fibers beyond that accomplished in the present study would further accentuate the delamination resistance. However, the chances of modifying the fiber orientation in sheets produced by wet methods are quite limited. As an example, an effort was made to improve the Z-directional characteristic by mixing, in different proportions, unbeaten long-fibered manilla rope pulp with highly beaten sulfite pulp. It was hoped that the presence of the beaten pulp in the sheet would force the long fibers out of their planar orientation. The maxima shown in two of the systems presented in Fig. 8 (other experiments showed a similar maximum) is interesting, although the reasons are obscure. The maxima are probably due to interplay between decreasing Z-orientation and fiber strength, on the one hand, and increasing fiber-to-fiber bonding by the addition of the highly beaten pulp on the other. In any case the effects are not large, particularly since the addition of beaten pulp reduces the maximum latex pickup considerably.

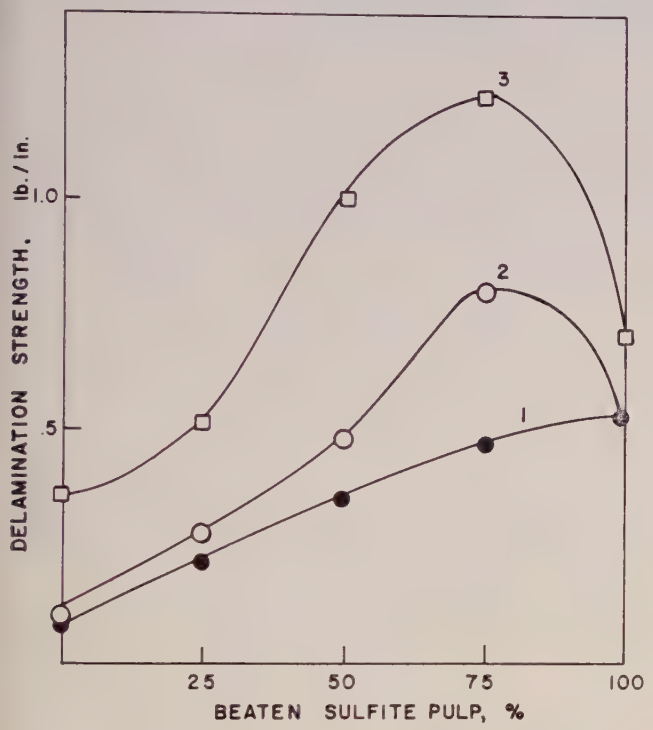

Fig. 8. Delamination strength of sheets prepared from various mixtures of beaten and unbeaten pulps

Curve 1: unbeaten sulfite mixed with highly beaten (C.S.f. 110) sulfite pulp. Curve 2: Manilla rope fibers in admixture with beaten sulfite pulp. Curve 3: the same mixtures as in Curve 1, saturated to 30% retention with Hycar latex.

It seems likely that dry methods of sheet preparation, such as are used in the production of nonwoven fabrics, may produce web structures better suited for high delamination resistance than is possible to accomplish by wet methods. Experiments in this direction would certainly be of considerable interest.

Another possibility, only incompletely explored in the present study, is to utilize beater addition rather than impregnation for the introduction of polymer into sheets. The presence of the attached latex particles should also result in a web with increased Z-orientation. Comparable machine-made sheets, made of kraft pulp with and without beater-added Butakon latex (a nitrile rubber), were obtained from Imperial Chemical Industries, Ltd., Welwyn Garden City, Herts, England. The Z-directional orientation and delamination strength are given in Table III. It appears, indeed, that the beater addition has had a pronounced effect on the fiber orientation.

Table III. Effect of Polymer Addition on the Z-Orientation of Paper

A. Direct impregnation of sheets made of various combinations of unbeaten and highly beaten sulfite pulps.

Highly beaten pulp, %	*Half-maximum angle, degrees, (002) diffraction*	
	Unsaturated paper	*30% Hycar saturation*
0	48.3	47.2
25	47.6	46.6
50	45.5	46.2
75	44.3	45.7
100	42.2	46.1

Beater addition of Butakon latex to kraft pulp, later converted to machine-finished paper on a foudrinier machine.

Butakon latex in paper, %	*Half-maximum angle, degrees, (002) diffraction*	*Delamination strength, lb./in.*
0	56.4	0.64
50	64.8	1.91
50	76.3	2.09

SUMMARY

The rheological properties of the polymers used as saturants appear to play a somewhat more pronounced role than the strength of the polymer-fiber bond. A large part of the energy consumed in the delamination process appears to be expended in deformational processes occurring in the paper or polymer-paper system. This may explain why rubbery polymers confer greater delamination resistance than would be predicted from normal tensile strength measurements. Non film-forming polymers such as polystyrene and easy-flowing polymers such as poly(2-ethylhexylacrylate) impart only minor improvements to the delamination resistance. The necessary balance of strength and modulus in the polymer shown for other paper properties (*8*) is probably also necessary with the delamination strength. However, the ultimate delamination strength is not only dependent on the kind of polymer used for impregnation, but is subject to substantial variations caused by the vehicle in which the polymer is introduced in the sheet. Aqueous latices and polymer solutions in benzene are superior to polymer solutions in hydroxylic solvents.

The effect of Z-directional fiber orientation on delamination properties has been demonstrated. The Z-directional fiber orientation can be improved by modifying the fibers prior to the sheet making process, or by disorienting the fibers in the paper web. Furthermore, certain indications were found for improved Z-orientation by beater addition compared with the impregnation of the sheets.

Briefly, it would appear as if at least three important factors are involved in the development of delamination resistance: (1) the Z-orientation of the fibers in the sheet, (2) the fiber-to-fiber bonding in the sheet, and (3) the degree of flexibility, i.e., the rheology of the

reinforced sheet as it affects its ability to absorb and dissipate the energy applied to the sheet during the delamination process.

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Further Studies on the Alkaline Hydrolysis of Palms

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The trunk "wood" and "bark," leaves, and petioles of cabbage palmetto (*Sabal palmetto*) were submitted to alkaline hydrolysis and the alkaline hydrolyzates were compared by means of qualitative and quantitative paper chromatography and spectrophotometry. *Sabal palmetto* "wood" chips were also cooked by the kraft process, and the black liquor was evaluated for phenolic compounds and compared with the alkaline hydrolyzates obtained from the various portions of the same plant. In all cases, *p*-hydroxybenzoic acid was the chief product of alkaline hydrolysis, but the yields of individual components varied greatly from portion to portion. Three species of bamboo of the *Phyllostachys* genus were also submitted to alkaline hydrolysis under the same conditions. These materials yielded *p*-coumaric acid as the chief product of alkaline hydrolysis.

Earlier studies on the alkaline hydrolysis of palms (*1*) indicated that the trunk material and petiole material of 26 representative species of palms (family Palmaceae), when subjected to alkaline hydrolysis, yielded ether-soluble products similar to those obtained from similar hydrolyses of representative hardwoods (*2*, *3*). In all instances, *p*-hydroxybenzoic acid was the chief product of alkaline hydrolysis of palm species. In the case of the cabbage palmetto (*Sabal palmetto*) it was demonstrated that the nature of the products produced by alkaline hydrolysis of trunk and petiole materials were qualitatively similar, but quite dissimilar quantitatively. This led to an investigation of other portions of the cabbage palmetto as a source of *p*-hydroxybenzoic acid and/or other identified compounds. The present paper reports studies on the alkaline hydrolysis of the leaves, trunk ("wood"), and rind ("bark") of cabbage palmetto. In addition, a kraft cook of cabbage palmetto "wood" chips was made, and the products of hydrolysis present in the black liquor were compared with those obtained in the other studies.

Palm fruit was also considered. The fruit of the cabbage palmetto was not available, so the common coconut, the fruit of *Cocos nucifera*, was studied. *Cocos nucifera* petiole material was hydrolyzed with alkali in the previous study (*1*). In the present paper, data for the coconut shell (endocarp), coconut meat (endosperm), and the fibrous membrane covering the meat (testa) are reported.

Because of the high yields of *p*-hydroxybenzoic acid in the alkaline hydrolyzates of the palms, it was desired to investigate other families of monocotyledonous angiosperms. The present paper includes introductory studies on three species of bamboo (family Gramineae).

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STARTING MATERIALS

A bolt of cabbage palmetto (*Sabal palmetto*) was obtained from Collier Co., Everglades, Fla. The "bark" was removed, and the trunk material was chipped and screened through a 4-mesh screen. These "wood" chips were employed for the kraft cook. Another portion of the trunk material was cut into sawdust and reduced in a Wiley mill to give "wood" meal for alkaline hydrolysis. The "bark" was also reduced in a Wiley mill to give "bark" meal for hydrolysis studies.

Sabal palmetto leaves and three bamboo species, *Phyllostachys vivax*, *P. bambusoides*, and *P. viridis*, were received from the U. S. Plant Introduction Station, Savannah, Ga. These products were reduced in a Wiley mill for alkaline hydrolysis.

The coconuts (*Cocus nucifera*) were obtained on the local retail market. They were cracked to give the shell material. This was broken up and then reduced in a micropulverizer to a fine powder. The brown fibrous membrane (testa) was removed from the white coconut meat, and both portions were allowed to air dry. The air-dried materials were extracted separately with ether in Soxhlet extractors and then ground to fine powders.

EXPERIMENTAL PROCEDURE

All the finely divided palm, coconut, and bamboo materials were subjected to alkaline hydrolysis as described previously (*2*). Hydrolyzates were processed and examined by means of qualitative paper chromatography and quantitative paper chromatography and spectrophotometry, as described in detail earlier (*1–4*).

Qualitative chromatograms of the ether extracts ob-

Table I. Known Compound Data for Alkaline Hydrolyses of *Sabal Palmetto* Materials

	"Wood"	*"Bark"*	*Leaves*	*Petiole*[a]	*Kraft cook of "wood" chips*
Ether extract,[b]	4.0	5.6	8.2	3.3	8.6
Vanillin, %[c]	0.5	0.3	0.1	0.4	0.2
Syringaldehyde, %	1.3	0.1	0.4	1.5	0.2
p-Hydroxybenzaldehyde, %	0.3	0.0	0.0	0.3	0.0
Acetovanillone, %	0.3	0.8	0.2	0.3	0.4
Acetosyringone, %	0.5	0.3	0.5	1.1	1.6
Vanillic acid, %	2.0	2.4	0.5	1.3	2.9
Syringic acid, %	2.7	0.8	0.6	1.3	2.9
p-Hydroxybenzoic acid, %	67.5	48.3	4.0	11.5	19.3
Ferulic acid, %	1.7	3.2	0.0	0.0	0.0
p-Coumaric acid, %	0.0	0.0	0.0	0.0	0.3

[a] Data from previous paper (*1*).
[b] The per cent ether extract is on the basis of the ovendry weight of starting material.
[c] The per cent of vanillin and all other compounds is on the basis of the ether extract.

Table II. Known Compound Data for Alkaline Hydrolyses of Coconut Materials

	Shell (endocarp)	*Membrane (testa)*	*Meat (endosperm)*	*Petiole*[a]
Ether extract, %[b]	4.6	2.6	2.8	2.8
Vanillin, %[c]	0.6	0.0	0.0	0.3
Syringaldehyde, %	0.2	0.0	0.0	0.4
p-Hydroxybenzaldehyde, %	0.0	0.0	0.0	0.0
Acetovanillone, %	0.3	0.0	0.0	0.3
Acetosyringone, %	0.3	0.0	0.0	0.6
Vanillic acid, %	1.8	2.3	3.0	2.4
Syringic acid, %	2.4	2.0	3.8	2.8
p-Hydroxybenzoic acid, %	38.3	2.3	5.6	25.4
Ferulic acid, %	0.8	0.0	1.6	2.8
p-Coumaric acid, %	0.0	0.0	0.0	2.6

[a] Data for petiole of *Cocos nucifera* from previous paper (*1*).
[b] The per cent ether extract is on the basis of the ovendry weight of starting material.
[c] The per cent of vanillin and all other compounds is on the basis of the ether extract.

Table III. Known Compound Data for Alkaline Hydrolyses of Three Bamboo Species

	Phyllostachys vivax	*Phyllostachys bambusoides*	*Phyllostachys viridis*
Ether extract, %[a]	4.4	3.7	4.0
Vanillin, %[b]	1.2	1.2	0.7
Syringaldehyde, %	0.6	0.8	1.3
p-Hydroxybenzaldehyde, %	1.7	1.7	0.7
Acetovanillone, %	0.4	0.4	0.4
Acetosyringone, %	1.9	1.0	1.0
Vanillic acid, %	2.0	3.4	2.8
Syringic acid, %	3.9	4.6	3.4
p-Hydroxybenzoic acid, %	1.6	3.2	3.8
Ferulic acid, %	5.3	4.4	5.3
p-Coumaric acid, %	25.9	30.3	35.5

[a] The per cent ether extract is on the basis of the ovendry weight of the starting material.
[b] The per cent of vanillin and all other compounds is on the basis of the ether extract.

Table IV. Data for Kraft Cook of *Sabal Palmetto* Chips

Digester charge, chips, g. O.D.	3951
Active alkali, NaOH as Na_2O, %	22.5
Sulfidity, Na_2S as Na_2O, %	25
Water ratio, cc./g. O.D.	6.64
Time to max. temp., min.	60
Time at max. temp., min.	30
Max. temp., °C.	172
Digester pressure at max. temp., lb.	104
Yield, % of total	32.2
Permanganate number	16.3

tained after acidification of alkaline hydrolyzates indicated that all of the compounds previously found in the petioles of palms (*1*) were present in the hydrolyzates of the present study. Quantitative data for the identified compounds found in hydrolyzates of various portions of *Sabal palmetto* are found in Table I, for the fractions of coconut in Table II, and for the three species of bamboo in Table III.

The *Sabal palmetto* chips were pulped by the kraft process in accordance with the schedule of Table IV. The pulp obtained was similar, but inferior to a similar pulp from aspen or birch. Approximately 5 gal. of black liquor was obtained, and the black liquor had a total solids content of 12.1%. An aliquot of the black liquor was acidified with dilute sulfuric acid and extracted continuously with ether in the air-agitated liquid-liquid extractor (*5*). The ether extract was concentrated under reduced pressure in a rotating evaporator, filtered to remove crystalline sulfur, and employed for solids determination and chromatographic studies. Qualitative chromatography indicated that all the compounds found in the alkaline hydrolyzate of *Sabal palmetto* "wood" and petiole materials (*1*) except *p*-hydroxybenzaldehyde were present in the black liquor from the kraft cook. Furthermore, *p*-coumaric acid was found in the black liquor, but was not found previously in the alkaline hydrolyzates of the "wood" and petiole materials. Quantitative data for the compounds found in the black liquor are included in Table I along with alkaline hydrolysis data for portions of the *Sabal palmetto*.

DISCUSSION OF RESULTS

Alkaline Hydrolysis of Sabal Palmetto Materials

The yields of ether extractives obtained upon alkaline hydrolysis of the several *Sabal palmetto* materials (see Table I) were all higher than corresponding yields from trunk and petiole materials of this species reported earlier (*1*). The several materials investigated yielded alkaline hydrolyzates with essentially the same ether-soluble components as determined by qualitative paper chromatography. Ferulic acid was found in only the alkaline hydrolyzates of the "wood" and "bark," *p*-hydroxybenzaldehyde in the hydrolyzates of only the "wood" and "petiole," and *p*-coumaric acid in none of the materials examined.

The quantitative results of the alkaline hydrolysis of *Sabal palmetto* materials are quite interesting. *p*-Hydroxybenzoic acid is the chief product of alkaline hydrolysis in all cases, but the actual yield is quite different for the several materials. The "wood" in the present study yielded 67.5% *p*-hydroxybenzoic acid on the basis of the ether extract, whereas in the earlier study (*1*), the yield was 81.3%. The present "bark" yielded 48.3% *p*-hydroxybenzoic acid, but the yield of ether extract was considerably more than in the case of the "wood." On the basis of the original starting material, the *p*-hydroxybenzoic acid yields from the "wood" and from the "bark" of the present *Sabal palmetto* were identical. This is not true for the other components of the alkaline hydrolyzates. Vanillic acid yields were essentially similar, but corresponding syringic acid yields were very dissimilar with the syringic acid being much higher in the case of the "wood." The same situation holds true for the acetovanillone-aceto-

syringone and vanillin-syringaldehyde situations. In all cases, the syringyl component comprised a much higher proportion of the hydrolyzate in the "wood" experiment than in the "bark" experiment. The leaves also contained more of the syringyl components than of the guaiacyl components. The considerably higher ferulic acid yield in the case of the "bark" hydrolysis over that obtained in the "wood" hydrolysis may be related to the lower yield of other guaiacyl compounds in the "bark" hydrolyzate. Moieties responsible for vanillin, acetovanillone, and vanillic acid in the "wood" experiment (*6*) are probably modified in the "bark" so that they yield ferulic acid on alkaline hydrolysis.

Alkaline Hydrolysis of Cocos Nucifera Materials

Alkaline hydrolysis of the portions of the coconut (*Cocos nucifera*) indicated that the coconut shell yielded essentially the same materials as did the petiole from the same species (*1*) (see Table II). However, in the present case of the coconut shell, the yields were somewhat different. In the case of *p*-hydroxybenzoic acid, the coconut shell yielded considerably more than did the petiole on the extract basis, and the shell also had a much higher yield of ether extract basis, and the shell also had a much higher yield of ether extract. Consequently, the coconut shell yielded more than double the amount of *p*-hydroxybenzoic acid on a weight basis than did the petiole of the same species, *Cocos nucifera*. Thus, the coconut shell appears to be a good source of *p*-hydroxybenzoic acid. The petiole of *Cocos nucifera* yielded a substantial amount of *p*-coumaric acid, whereas no portion of the fruit of this species yielded any of the acid whatsoever. The yield of *p*-coumaric acid in the case of the petiole may be related to the lower yield of *p*-hydroxybenzoic acid in the same experiment.

It should be noted that no phenolic carbonyl compounds were found in the alkaline hydrolyzates of either the coconut meat or the membrane substance around the meat (endosperm and testa, respectively). Thus, moieties such as those probably responsible for the aldehydes and ketones in representative hardwoods (*6*) and palm petioles (*1*) are probably absent in the endosperm and testa of coconuts. In the case of the endosperm and testa the yields of *p*-hydroxybenzoic, vanillic, and syringic acids are all in essentially the same range. Thus, it is possible that, in this instance, these three acids are produced by the same type of mechanism from the same type of configuration in the starting material.

Kraft Cook of Sabal Palmetto "Wood" Chips

The *Sabal palmetto* "wood" chips yielded a pulp very similar to that obtained by similar cooking of aspenwood, but the yield was somewhat lower, both on a weight and on a volume basis. The black liquor obtained yielded a higher percentage of ether extractives on the original "wood" basis than did an alkaline hydrolysis on the same material. However, yields of individual components were quite different on both a qualitative and quantitative basis. The presence of sodium sulfide and/or the higher temperature of the kraft cook must have been responsible for these differences. The yield of *p*-hydroxybenzaldehyde disappeared entirely in the kraft cook, but *p*-coumaric acid was obtained. In fact, the kraft cook is the only experiment performed on any *Sabal palmetto* material which yielded *p*-coumaric acid. This finding was unexpected because in the case of similar experiments on aspen (*7*) substantial quantities of *p*-coumaric acid were found on alkaline hydrolysis, but none whatsoever was found after kraft cooking of the same wood. Another unexpected result was the comparison of *p*-hydroxybenzoic acid yields in the alkaline hydrolysis and kraft cooking experiments on *Sabal palmetto* "wood." Even taking into account the difference in yield of ether extract, the yield of *p*-hydroxybenzoic acid is much less after kraft cooking. In the similar case of aspen (*7*) the yield of *p*-hydroxybenzoic acid was higher after kraft cooking of the wood than it was after alkaline hydrolysis. On the original "wood" basis, *Sabal palmetto* yielded much more acetovanillone, acetosyringone, vanillic acid, and syringic acid after a kraft cook than it did after alkaline hydrolysis. Discussions noted earlier for aspenwood (*7*) probably apply in the present instance.

Alkaline Hydrolysis of Bamboo Species

The three species of the *Phyllostachys* genus tested by the alkaline hydrolysis procedure gave essentially the same results although minor quantitative differences appeared for the individual species (Table III). The yields of the related vanillic, syringic, and *p*-hydroxybenzoic acids appeared to be in the same general range and were probably formed by the same type of hydrolysis reaction. This same type of reaction may also have been responsible for the ferulic acid formed, although in two out of three cases, ferulic acid yields were much higher than those acids with only one carbon side chain. In all cases, the chief component of the alkaline hydrolyzate was *p*-coumaric acid, a situation reminiscent of the alkaline hydrolysis of *Populus tremuloides* bark (*8*). However, in the present instance with *Phyllostachys* species, the yield of *p*-coumaric acid was much higher. In fact, fractional crystallization of the ether extractives obtained from the alkaline hydrolyzates of any of the *Phyllostachys* species studied yielded crystals of *p*-coumaric acid melting at 208 to 210°C. which did not depress the melting point of a mixture with authentic *p*-coumaric acid. Thus, bamboos of the *Phyllostachys* appear to be a good source of *p*-coumaric acid.

In the case of *Populus tremuloides* bark it was shown that *p*-coumaric acid might have originated from glucosides (*9*). Whether or not glucosides are responsible for the *p*-coumaric acid in the alkaline hydrolyzates of the *Phyllostachys* species of the present investigation must await future studies. These studies along with those of other bamboo genera will be published in continuing papers.

SUMMARY

Various portions of the cabbage palmetto tree were submitted to alkaline hydrolysis, and the alkaline hydrolyzates were compared by means of qualitative chromatography, quantitative chromatography, and spectrophotometry. Included in the study were kraft pulping liquors of palmetto wood chips and hydrolysis liquors from three bamboo species.

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RECEIVED April 12, 1961.

Free Surface Instability*

A Final Report on TAPPI Project No. 156

WALTER R. DEBLER

An improved apparatus to simulate the wrapping of the wire on a table roll of a fourdrinier machine was constructed. This apparatus permits the convenient and systematic study of the post roll spouting phenomena. New data were obtained which agree with previous preliminary results. Two "stepdowns" (representing wire wrap conditions) were investigated at different Froude numbers, and some exploratory information was gathered with a second size of table roll. The character of the spouting obtained with the laboratory apparatus closely reproduces that obtained on the actual fourdrinier machine. The growth of the disturbance increases with Froude number and the extent of the "stepdown," i.e., the slackness of the wire. These results are consistent with the experience of paper producers.

THE SPOUTING of the paper stock, which usually occurs after each table roll of a fourdrinier machine operating at high speed, can adversely affect the quality of the paper produced. Because this machine is so extensively employed in the production of paper it is advantageous to the manufacturer to be able to control the degree of stock spouting and thereby increase his operating efficiency. Since 1958 members of the Engineering Mechanics Department of The University of Michigan have been studying, analytically and experimentally, the instability problems of a liquid with a free surface. Such an investigation is aimed at determining the importance of the pertinent parameters with regard to the instability, the possible cause of the spouting.

The experimental study of the post roll spouting phenomena initiated in 1958, and reported by Yih and Spengos (*1*), was continued during 1959. The purpose of this investigation was to gather laboratory data concerning the growth of the free surface wave disturbance that occurs after the table rolls of a fourdrinier paper machine. These data would provide additional information against which any theory that attempted to explain the spouting could be weighed.

EXPERIMENTAL

The experimental work was carried out with the apparatus shown in Figs. 1, 2, and 3. This apparatus is basically the one which was used in the original investigation (*1*) but embodies several improvements

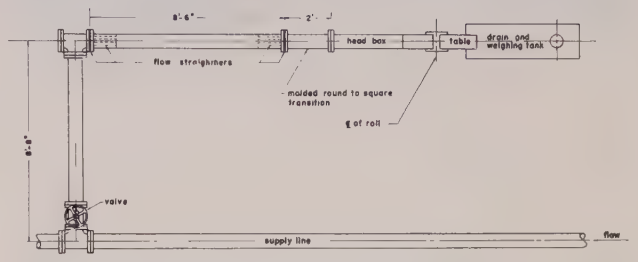

Fig. 1. Plan view of experimental apparatus

that were suggested as a result of the previous work.

A section of straight pipe was installed in the system to improve the inlet flow conditions into the section which simulated the "headbox" of the actual paper machine. This piece of pipe was fitted with "honey comb" flow straighteners at both ends, along with screens at the upstream end. At the end of the pipe a transition section was fitted, which provided a gradual change from the round pipe to the square cross-section of the "headbox."

The top surface of the "headbox" was slightly concave to provide for the effective collection and removal of the air that had been previously entrained in the water supply and which had come out of solution. The air was removed by draining off a small quantity of water from the vicinity of the upper surface by means of pet cocks. This small flow induced the collected

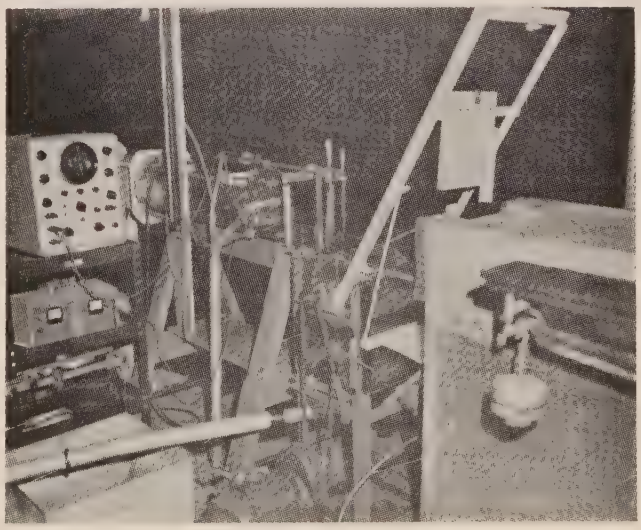

Fig. 2. Experimental apparatus

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* This study is a project of the Fluid Mechanics Committee, and has been financed by TAPPI Grant No. 156.

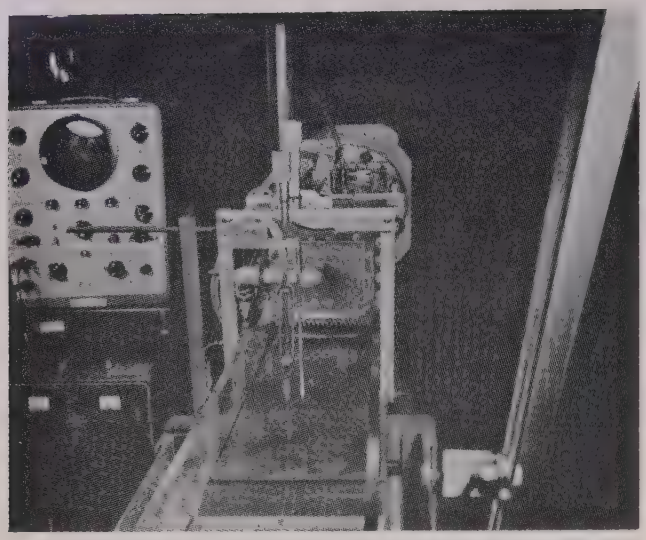

Fig. 3. Experimental apparatus, showing pitot tube, electric probe for measuring surface elevation, and serrated headbox opening

air pocket to pass out also through the pet cock. Previously, this air collected along a flat upper surface where it was not readily removable. The pocket of air would grow until it became unstable and a segment would break off and pass out of the "headbox" via the opening at the downstream end. This action disturbed the readings that were being taken further downstream.

The downstream portion of the "headbox" was internally shaped to provide a gradual transition from the square cross-section to the rectangular opening at the end. This converging section was formed by having a curved piece of plastic serve as the upper flow boundary. The plastic had many small holes drilled perpendicularly to its surface, and water was drawn continuously through these holes. In this way it was intended to provide a free surface flow that would be devoid of the influence of the eddy that would otherwise be produced in the corner of the "headbox," and also be free of the disturbances resulting from the introduction of the curved surface.

The flow issued out of the "headbox" via rectangular opening at the end (see Fig. 3). The upper portion of the opening was fitted with a serrated surface, which generated the free surface disturbance that traveled

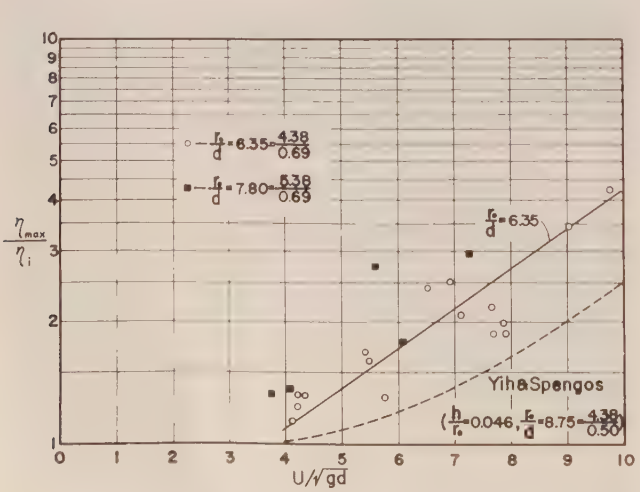

Fig. 4. Growth of disturbances downstream from the table roll ($h/r_o = 0.046$)

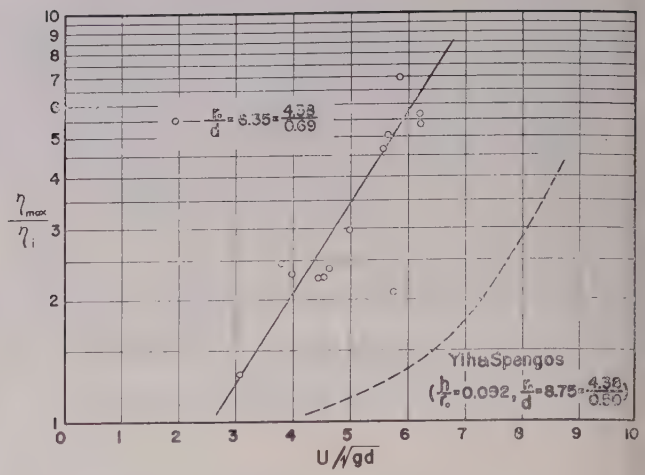

Fig. 5. Growth of disturbances downstream from table roll ($h/r_o = 0.092$)

onto the revolving drum that simulated the table roll on the paper machine. The spacing and height of the serrations—$^1/_4$ in. and $^1/_4$ in., respectively—that were used differed from that previously employed. Upon the advice of Mr. C. Lamb, Kimberly-Clark Corp., Neenah, Wis., the thickness of the serrated piece (measured in the direction of the flow) was increased, and a value of $^1/_2$ in. was used. It should be pointed out that no investigation was conducted to determine the optimum size and shape of either the converging section located at the downstream end of the "headbox" or the serrated piece that initiated the free surface disturbance.

The revolving drum used in the previous experiments was retained; however, an aluminum drum of $10^3/_4$ in. diameter was made and some limited data were obtained with it.

The height of the post roll disturbance was measured with the electric probe that had been used in the earlier investigation (see Fig. 3). An oscilloscope was connected to the probe and a small voltage difference existed between the probe tip and the water. Thus, when the tip contacted the wave crests, a periodic movement of the trace of the oscilloscope occurred, and when the probe was moved to the elevation of the wave trough, a nearly constant displacement of the trace occurred.

Considerable work was done to obtain photographs which would yield quantitative data, but only qualitative results were achieved. Apart from the inherent parallax distortion, the major difficulty was that of measuring the wave amplitude from the photographs. While the absolute elevation of the wave crests could be measured, the elevation of the troughs remained undetermined from the photographs.

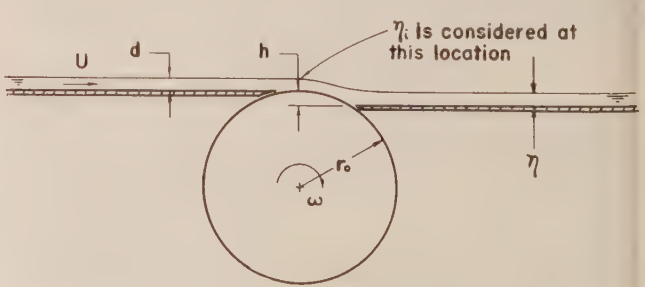

Fig. 6. Definition sketch

It is conceded, however, that further work in the area of photographic measurement could be fruitful. Indeed, the electric probe measurements become increasingly difficult to make and subject to uncertainty as the waves begin to become unstable and spray is formed. In this region of testing a photographic method would be valuable. The opposite is true for the case of small disturbances. In this situation it is believed that the degree of precision available from scaling a photograph would be sufficient only to yield qualitative results.

RESULTS

The data obtained in the course of the experimental work are presented in Figs. 4 and 5. These data can best be interpreted in the light of the dimensional analysis performed by Yih and Spengos (*1*). The result of this analysis shows that:

$$\frac{\eta}{\eta_i} = f_1\left(\frac{h}{d}, \frac{r_0}{d}, \frac{Td\rho}{\mu^2}, \frac{Ud\rho}{\mu}, \frac{U}{\sqrt{gd}}\right) \qquad (1)$$

in which U is the average velocity of the liquid; T, the surface tension of the liquid; μ, the dynamic viscosity; ρ, the mass density; g, the gravitational constant; and f_1 is some functional relationship which must be determined. The remaining geometric quantities are defined in Fig. 6.

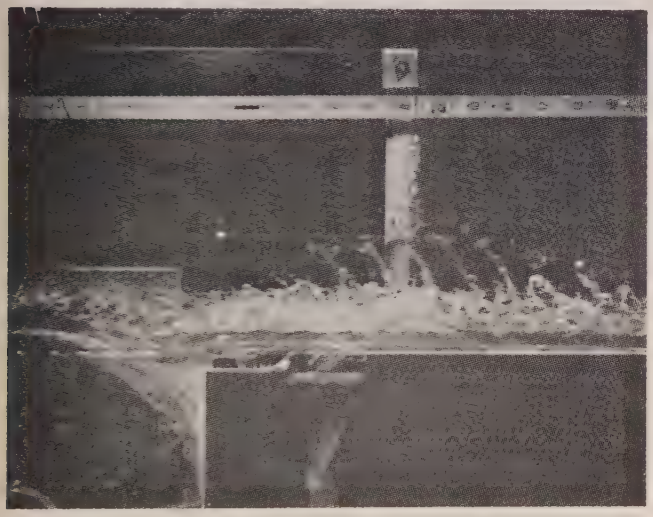

Fig. 7. Side view of post roll spouting ($U/\sqrt{gd} = 7.04$, $h/r_0 = 0.092$)

For the data which are presented all the physical properties of the liquid were kept essentially constant, and if the viscous effects are neglected, but the surface tension effect is retained, the relationship described in equation (1) reduces to:

$$\frac{\eta}{\eta_i} = f_2\left(\frac{h}{r_0}, \frac{r_0}{d}, \frac{T}{U^2d\rho}, F\right) \qquad (2)$$

in which:

$$F(\text{Froude number}) = U/\sqrt{gd}$$

In the presentation of the data $\eta_{max.}/\eta_i$ is plotted, as this ratio is the one of greatest practical interest. One can see from the results that this ratio increases with F and h/r_0, a fact which appears to be reasonable. In addition some limited data are presented for the case of $h/r_0 = 0.0461$ which shows the influence of changing r_0/d by increasing r_0 from 4.38 to 5.38 in., an increase of this parameter of 22.8%. From these preliminary results it appears that spouting is increased by increasing the roll size alone.

By comparing the experimental results of Yih and Spengos (*1*) it is apparent that the present data agree in the nature of the trend but indicate higher values of $\eta_{max.}/\eta_i$ at a given value of F and h/r_0. This variance can be attributed to the fact that there was a difference in the dimension d that was used in the two experiments (0.5 in. previously, and 0.69 in. for the current data). This change affects both $T/U^2d\rho$ and r_0/d. Concerning the first parameter, increasing d has the same effect as decreasing surface tension and naturally leads to greater amplification. As to the effect of the change of the second parameter the results show that $\eta_{max.}/\eta_i$ increases as $U/\sqrt{gd}$ is increased or as r_0/d is decreased. The increase of $\eta_{max.}/\eta_i$ with decreasing r_0/d is in agreement with Yih's analysis (*2*) for stability of a rotating film over a table roll. Evidently this situation still prevails after the table roll. The analytic work of Yih (*2*) was also done under TAPPI project 156.

The form of the disturbance is seen in Figs. 7 and 8. The occurrence of the maximum amplitude (i.e., $\eta_{max.}$) downstream of the roll and the well-defined transverse spacing of the disturbance is evident. Indeed, the spouting generated in the laboratory bears a striking resemblance to that observed in the fourdrinier machine.

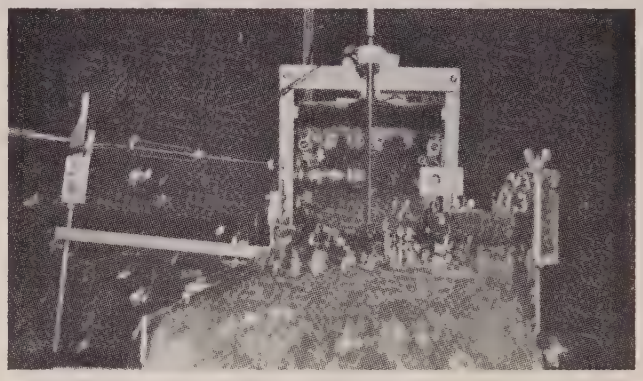

Fig. 8. End view of post roll spouting ($U/\sqrt{gd} = 7.04$, $h/r_0 = 0.092$)

CONCLUSIONS

1. The disturbances which occur subsequent to the table rolls have been reproduced by the laboratory apparatus shown in Fig. 2.

2. The growth of the disturbances subsequent to the table rolls were determined with the laboratory apparatus and the results are shown in Figs. 4 and 5. It appears that the flow becomes increasingly unstable as $U/\sqrt{gd}$ increases or as r_0/d decreases. The precise effects of viscosity and surface tension are still to be determined.

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The resourceful experimental assistance rendered by Mr. A. Engerer is greatly appreciated.

Attempted Degradations of Spruce Formaldehyde–Periodate Lignin

M. R. JAIN and C. B. PURVES

A published method was used to condense the periodate lignin with about 32 parts of formaldehyde dissolved in 73% sulfuric acid, and the major product (Ross-Potter lignin) was precipitated by water. Yield, 104% by weight of the periodate lignin. The failure of the formaldehyde lignin to yield vanillin when suitably oxidized was confirmed; also the fact that thorough oxidation with alkaline potassium permanganate or with iodic acid yielded 4.7% of benzene hexa- and pentacarboxylic acid, but no benzene-1,2,4,5-tetracarboxylic acid. A convenient separation of these acids on a cellulose column was discovered. These results, and the failure of formaldehyde lignin to sulfonate in a sulfite cook, suggested that some of the formaldehyde had condensed in the α-positions of the phenylpropane building stones of lignin. To facilitate later structural studies, formaldehyde lignin was submitted to the following reagents and the percentages that became dialyzable in aqueous solution through cellophane were used as a preliminary measure of the degradation produced: methanolysis, 5%; sulfonation at pH 5 and 98°C., 14 to 20%; hydrolysis at pH 2 and 135°C., 0%; sodium azide in concentrated sulfuric acid (the Schmidt reaction), 25% of a black, nitrogenous gum; boron trifluoride in boiling benzene, 7%; hydriodic acid (47%) at 50°C., 13% of a yellow-brown gum. Although most of this gum traveled on chromatograph paper as a single substance, it was still a mixture.

Ross and HILL (*1*), and Ross and Potter (*2*), noticed many years ago that wood soaked in formalin gave no residue of Klason lignin when mixed with 72% sulfuric acid, but dissolved completely. The lignin separated only when this solution was diluted with water, and the yield from softwoods appeared to be nearly quantitative: hardwoods gave smaller yields (1, 3). These observations (*2*) suggested that the solubility of formaldehyde lignin (or Ross-Potter lignin) originated in a preferential condensation of formaldehyde with the lignin at reactive sites which, unless "blocked" in this way, condensed among themselves to give the insoluble Klason lignin. A similar explanation would account for the discovery by Hägglund, Kullgren, and their associates, that lignin had to be sulfonated to an insoluble stage I lignosulfonic acid before it could be successfully hydrolyzed to soluble products (*4*). Since it was possible that the same reactive sites became substituted either with formaldehyde or with sulfonic acid groups, a more detailed study of formaldehyde lignin was desirable. This task was commenced by Eisenbraun and Purves (*5*), and the present article describes a continuation of their work. The lignin used was prepared from spruce wood meal by the preferential oxidation of the carbohydrates with aqueous periodic acid (*6*). Although somewhat oxidized itself, the residual periodate lignin pulped at nearly the normal rate in an acid sulfite cook, and had the advantage that carbohydrates from the wood were no longer present to complicate the experimental work.

Eisenbraun and Purves (*5*) made the usual assumption that the major structural component in spruce lignin was an oxygenated phenylpropyl unit (I) in which the location of the oxygen atoms in the side-chain was arbitrary (see Fig. 1). The consumption of formaldehyde, and also the content of radioactive C^{14} when C^{14}-formaldehyde was used, suggested that structure I first acquired the two hydroxymethyl groups marked with an asterisk in II. The yield, carbon, hydroxy, and methoxy content of the product actually isolated, however, showed that at least 1 mole of water was lost to give a structure such as III, which retained solubility because it was not cross-linked. Although structure III accounted for the failure of formaldehyde lignin to yield vanillin when oxidized with nitrobenzene and alkali, the presence of oxygen substituents in the aromatic rings would produce nothing but oxalic, acetic, and carbonic acid when the oxidant was alkaline potassium permanganate (*7*). The isolation of several per cent of benzenepentacarboxylic acid (and possibly some of the hexacarboxylic acid) in the latter oxidation made it plausible to assume a lignan structure as a minor component of the lignin macromolecule.

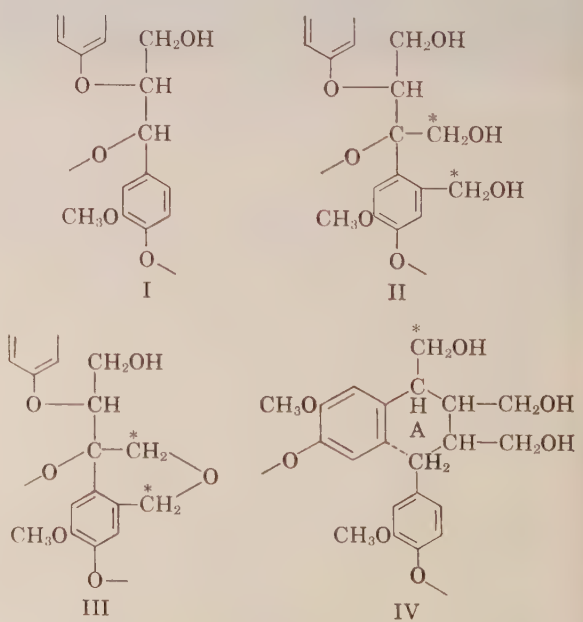

Fig. 1

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Article abstracted from Ph.D. thesis submitted by M. R. Jain to McGill University in September, 1960.

Substitution of formaldehyde in the alpha position of the lignan would give a structure such as IV which, when cyclized as shown by the broken line, would yield a new cyclohexene ring (A) unsubstituted by oxygen atoms. Oxidation of IV with alkaline potassium permanganate would then be expected to yield benzenehexacarboxylic (mellitic) acid, and by partial decarboxylation, the benzenepentacarboxylic acid actually isolated.

When the oxidations of formaldehyde lignin with nitrobenzene or cupric hydroxide in alkali were repeated during the present research, the liquors were chromatographed on paper with developing systems and sprays known to separate and detect simple phenolic acids as well as phenols like vanillin. A vanillin-2-carboxylic acid, for example, might have arisen by an oxidative cleavage of structure III. The absence of spots of any kind on the chromatograms, however, was confirmed, and the probability of a substituent on the alpha carbon atom of III was strengthened.

One limitation in repeating the more drastic oxidations of formaldehyde lignin with alkaline potassium permanganate, or with iodic acid, was that the solvent systems previously used to separate the benzene polycarboxylic acids in paper chromatography (*5*, *8*) did not readily move mellitic acid from the starting line. This result, however, was attained by elution with 5% aqueous formic acid, and it became possible to resolve a mixture of benzene hexa-, penta-, and 1,2,4,5-tetracarboxylic acids quantitatively by elution from a cellulose column, first with a methyl isobutyl ketone–water mixture and then with the aqueous formic acid. The oxidation of the formaldehyde lignin yielded 1.2, 3.5, and 0.0% of the benzene hexa-, penta-, and 1,2,4,5-tetracarboxylic acids, respectively, and thereby confirmed the earlier work quantitatively. Since the corresponding figures from the oxidation of periodate lignin were 0.0, 2.9, and 0.8%, the substitution of formaldehyde in the lignin caused the disappearance of the tetra-acid and the appearance of the hexa-acid, as suggested by structure IV.

Since future attempts to elucidate the structure of formaldehyde lignin will probably require structural fragments of low molecular weight as starting materials, the remainder of the present research was devoted to brief studies of various methods of degradation. A search was made in each case for the mildest possible conditions, in order to render less probable an inner condensation to more complex,. less soluble products. Although compounds of considerable molecular weight (several thousand) were known to pass in aqueous solution through cellophane, the percentage of the formaldehyde lignin that could be dialyzed was used as a preliminary measure of degradation.

METHANOLYSIS AND SULFITE COOKS

Degradation by methanolic hydrogen chloride gave the results summarized in Fig. 2 (top), 20% of the formaldehyde lignin becoming soluble in water, and a further 10% of "methanol formaldehyde" lignin retaining solubility in methanol but not in water. Practically the same results were obtained when the duration of methanolysis, or of ethanolysis, was reduced from 24 hr. to 1 hr. The next step was to omit the hydrogen chloride and to extract the dry formaldehyde

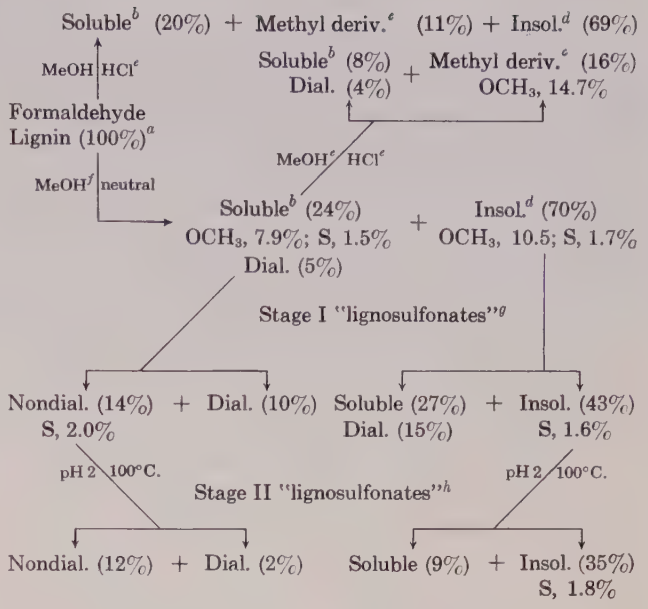
Soluble[b] (20%) + Methyl deriv.[e] (11%) + Insol.[d] (69%)
MeOH HCl[e]
Soluble[b] (8%) + Methyl deriv.[e] (16%)
Dial. (4%) OCH3, 14.7%
Formaldehyde Lignin (100%)[a]
MeOH[e] HCl[e]
MeOH[f] neutral
Soluble[b] (24%) + Insol.[d] (70%)
OCH3, 7.9%; S, 1.5% OCH3, 10.5; S, 1.7%
Dial. (5%)
Stage I "lignosulfonates"[g]
Nondial. (14%) + Dial. (10%) Soluble (27%) + Insol. (43%)
S, 2.0% Dial. (15%) S, 1.6%
pH 2 100°C.
pH 2 100°C.
Stage II "lignosulfonates"[h]
Nondial. (12%) + Dial. (2%) Soluble (9%) + Insol. (35%)
S, 1.8%

Fig. 2. Methanolysis and attempted sulfonation of spruce formaldehyde-periodate lignin

[a] Percentage yields given in brackets based on the original formaldehyde lignin. "Dial." = dialyzable, and "nondial" nondialyzable, in aqueous solution through cellophane. Analytical data quoted on an ash-free basis.
[b] Soluble in methanol and water.
[c] Soluble in methanol; insoluble in water.
[d] Insoluble in methanol and water.
[e] Under reflux in 2% methanolic hydrogen chloride for 1 to 24 hr.
[f] Under reflux for three extractions; each for 30 min.
[g] Soluble and insoluble fractions separately heated in 16% aqueous sodium bisulfite (pH ~ 5) at 98°C. for 20 hr.
[h] Maintained at 100°C. for 24 hr. at pH 2.

lignin with boiling neutral methanol, which removed material of lower methoxyl content but completely soluble in water. When this material was submitted to methanolysis, a portion acquired an increased methoxyl content and became insoluble in water. Since the dialyzable portion was not increased, methanolysis did not appear to be an efficient method of degradation. Certain oxygenated phenylpropane "monomers" of lignin examined by Hibbert and his collaborators (*9*, *10*) also gave less soluble resinous products under the action of alcoholic hydrogen chloride.

The lower half of Fig. 2 describes attempts to sulfonate the methanol-soluble and -insoluble portions of formaldehyde lignin, the conditions used being adequate to convert periodate lignin to an insoluble stage I lignosulfonate (S ~ 3%). Sulfonation doubled the amount of the soluble portion that could be dialyzed, and produced substantial amounts of soluble or dialyzable material from the insoluble portion. Two of these fractions were then hydrolyzed as in the conversion of a stage I to a soluble stage II lignosulfonic acid in 90% yield (*4*); the increase in dialyzable material was minor, although a further 9% of the formaldehyde lignin was rendered soluble. A repetition of these experiments with the unfractionated lignin gave corresponding percentages (not shown in Fig. 2), and 38% remained undissolved after sulfonation and hydrolysis. This fraction probably came from the component that was insoluble in methanol (Fig. 2, 70% → 35%).

The dialyzable products (Fig. 2) were associated with much sodium bisulfite, and in order to decrease

this contamination the ratio of the bisulfite to the formaldehyde lignin was reduced in stages. Many small-scale experiments showed that the amount of the lignin that dissolved increased from 30 to 100% as the concentration of the aqueous sodium bisulfite decreased from 16 to 1%; the solids-to-liquor ratio could be reduced to 1:20, and the time of heating from 20 hr. to 1 hr. without changing this result. Throughout these experiments, the dialyzable portion remained within the limits 13.5 to 16%. A larger-scale extraction of the formaldehyde lignin was then carried out with 1% sodium bisulfite for 1 hr. at 98°C., and the resulting black liquor yielded a soluble, nondialyzable light-brown powder (85%) which was used in later experiments as fraction A.

The product from the dialyzate was a light-yellow powder from which much sodium bisulfite was removed by virtue of its sparing solubility in methanol. Failure to reduce the sulfur content of the remainder by the elimination of any sulfate or sulfite ions created the possibility that this portion consisted of a lignosulfonic acid averaging 2 methoxyl and 1 sulfonic acid groups in a base molecular weight of about 500. With this possible exception, the bisulfite cooks failed to increase the sulfur content of the formaldehyde lignin significantly from the original value of 1.6% (Fig. 2), which originated from the 73% sulfuric acid used in its preparation. The failure to sulfonate was attributed to the substitution of sulfonatable sites by the formaldehyde rather than to the condensing action of the 73% sulfuric acid, because the corresponding Klason lignin (S, 0.35%) yielded a stage I lignosulfonic acid (S, 2.5%) when cooked in 16% aqueous sodium bisulfite. Nevertheless, the bisulfite appeared to have a specific action, perhaps of peptization, upon the formaldehyde lignin, because parallel cooks in buffers at pH 5 rendered only 10% dialyzable. Fraction A became insoluble when the acidic, ash-free form was freeze-dried, and similar treatment of the corresponding dialyzable material, 13.5%, left only 10% dialyzable. Such treatments were therefore similar to the condensing action of methanolysis.

THE SCHMIDT REACTION

The left-hand column of Table I records all of the present attempts to degrade formaldehyde lignin to a dialyzable condition, and adjustment is made in the middle column for the soluble nondialyzable and dialzyable by-products also formed in the condensation of periodate lignin with formaldehyde (*5*). According to reviews by Wolfe (*11*) and Smith (*12*), the condensation of carbonyl compounds with hydrazoic acid in strong mineral acid (the Schmidt reaction) often resulted in the formation of an acid amide with cleavage of the carbon skeleton:

$$R{-}CO{-}R_1 + HN_3 \xrightarrow{H^+} R{-}NH{-}COR_1 + N_2$$

Vanillin, for example, was found by Schuerch (*13*) to yield 70% of vanillonitrile, although the amide was presumably first formed; veratraldehyde behaved similarly. Sometimes unsaturated compounds, or those containing secondary or tertiary hydroxyl groups, yielded Schiff bases:

$$C_6H_5{\cdot}CH(OH)\ C_6H_5 + HN_3 \xrightarrow{H_2SO_4} C_6H_5{\cdot}CH{=}NC_6H_5 + H_2O + N_2$$

Table I. Conversions of Formaldehyde Lignin and Periodate Lignin to Dialyzable Materials

	Formaldehyde lignin		*Periodate lignin*
	%	*Corr.,*[a] %	
Neutral Methanol			
Total yield	100	92	100
Insol. H_2O	70	64	100
Nondialyzable	19	22	...
Dialyzable	5	9	...
Methanolysis[b]			
Insol. H_2O	80	74	70
Nondialyzable	~16	18	19
Dialyzable	~4	8	
Stage I Sodium Bisulfite Cooks[c]			
Insol. 16% $NaHSO_3$	44	41	80[d]
Nondialyzable	35	36	20[d]
Dialyzable	21	23	
Hydrolyses to Stage II[e]			
Insol. at pH 2	38	34	9[d]
Nondialyzable	42	42	91[d]
Dialyzable	~20	~23	
% of Fraction A[g]			
Schmidt Reaction[f]			
Crude yield	300	235	134
Insol. *N* NaOH	70	55	44
Nondialyzable	5	8	27
Dialyzable	25[h]	36	29[h]
Boron Trifluoride[i]			
Crude yield	200	156	130
Insol. aq. Na_2CO_3	5	4	...
Nondialyzable	132	106	...
Dialyzable	69	70	...
Aluminum Tribromide[j]			
Crude yield	112	91	98
Insol. *N* NaOH	75	59	70
Nondialyzable	18	18	15
Dialyzable	7	22	13
Hydriodic Acid[k]			
Crude yield	96	...	
Insol. *N* NaOH	71	56	77[l]
Nondialyzable	8	13	12[l]
Dialyzable	13	30	

[a] Corrected to a periodate lignin base; this lignin gave insoluble formaldehyde lignin, nondialyzable and dialyzable material in approximate ratio 92:4:4 by weight.
[b] In boiling 2% methanolic hydrogen chloride for 18 hr.
[c] In 16% sodium bisulfite at 97°C. and pH 5 for 20 hr.
[d] Ref. (*6*); soluble portion not dialyzed.
[e] In water at pH 2 and 98°C. for 24 hr. Insoluble stage I portion (44%) gave only 6% of soluble material which was included in the 42% quoted.
[f] Sodium azide in concentrated sulfuric acid near 0°C.
[g] Fraction (85%) of formaldehyde lignin soluble in 1% sodium bisulfite at 98°C. but nondialyzable; remaining 13.5% dialyzable. Periodate lignin base: fraction A, soluble but nondialyzable, and dialyzable material in approximate ratio 78:4:16.4 by weight.
[h] Not isolated; yield obtained by difference.
[i] In acetic anhydride at 122°C. The products were acetylated.
[j] An 8% solution in boiling benzene.
[k] A 47% solution at 50°C. for 8 hr.
[l] Ref. (*20*). Found for insoluble portion: OCH_3, 9.4; I, 3.1%. Found for soluble portion: OCH_3, 11.9; I, 18.2%.

When the nondialyzable formaldehyde lignin fraction A was submitted to the Schmidt reaction, a black gum insoluble in dilute sulfuric acid resulted in very large yield. The portion of this gum insoluble in aqueous alkali, and also the soluble but nondialyzable portions, were dark resins containing about 4% each of sulfur and nitrogen. The large dialyzable fraction was not examined because it was heavily contaminated with salts.

ETHER-CLEAVING AGENTS

Although the sulfuric acid used in the condensation with formaldehyde had probably hydrolyzed the more labile ether links in the lignin, the stability of the remaining links toward other known ether-cleaving reagents was tested. The first of these reagents was boron trifluoride in acetic anhydride, which Francis and Rudloff (*14*) recently used to cleave several hydroxytetrahydropyrans and anhydrosugars. Although insoluble in aqueous sodium carbonate, the

main product from fraction A, a brown powder, was almost completely soluble in water and much was dialyzable. The latter portion was not examined, because it was contaminated with black by-products from the reagents, and differed markedly from lignin in being transparent to ultraviolet light throughout the wavelength range 200 to 400 μ. Aluminum tribromide was another Lewis base known to cleave aryl alkyl ethers, but not diaryl ethers (*15*, *16*, *17*). Little of the formaldehyde lignin A, or of periodate lignin (Table I, right-hand column), was degraded to a dialyzable condition by this reagent, but the former was extensively demethylated (OCH_3, 5.3%) whereas the latter was not (OCH_3, 11.2%). Since the reagent as used readily demethylated *p*-dimethoxybenzene to hydroquinone but left vanillin largely unchanged, it appeared that the stability of some of the methoxy groups was diminished when lignin was condensed with formaldehyde.

Irvine and Hynd (*18*) hydrolyzed 2,3,4,6-tetra-O-methyl-D-glucose to glucose with 45% hydriodic acid at 95°C., and were apparently the first to use this acid under controlled conditions as an ether-cleaving agent. Brownstein (*19*) and Wieckowski (*20*) then found that 47% hydriodic acid at 50°C. hydrolyzed benzyl ethers such as diveratryl ether and *p*-methoxybenzyl guaicyl ether, but that diaryl and other types of aryl alkyl ethers were unaffected. When the formaldehyde lignin fraction A was exposed to the same reagent, 4% with a low methoxyl content was recovered from the liquor, while the residue (92%) retained the original methoxyl content and acquired only a trace of iodine. An alkaline extract of this residue yielded 13% of a dialyzable yellow gum of which about three-quarters (10%) traveled with R_f 0.26 on a paper chromatogram with butanol saturated with 2% aqueous ammonia as the eluent. Since this was the only major degradation product encountered that moved from the starting line in paper chromatograms, a larger sample was prepared and was purified on a cellulose column. The thick, yellow-brown syrup contained a minor component which crystallized, but the mixture was not satisfactorily resolved by the methods tried. The syrup gave ultraviolet and infrared absorption spectra characteristic of most lignins and of the phenolic group. Since a parallel hydrolysis of spruce wood meal with hydriodic acid failed to yield the product of R_f 0.26, a detailed study of this mixture might eventually throw light on the structure of formaldehyde lignin. Of the other methods of degradation noted in Table I, the Schmidt reaction, and perhaps the sodium bisulfite cook, also appeared promising enough to justify further study.

EXPERIMENTAL

Materials and Methods

The black spruce wood meal, from the log previously used, was alternately oxidized with sodium periodate near pH 4 and 20°C., and extracted with cold 0.1 *N* NaOH (*5*). The residual water-wet lignin was freeze-dried.

Found: OCH_3, 12.0; ash 1.0; apparent holocellulose, 0%.

Unless stated otherwise, evaporations were carried out under diminished pressure at 40 to 50°C. in a rotatory evaporator, and samples were dried over phosphorus pentoxide under vacuum and at room temperature. Analyses were quoted as the mean of concordant duplicates, and references to routine methods were given in the previous publication (*5*). Values for sulfated ash were omitted, since almost always they were only slightly greater than those quoted for ash. All yields and analyses were corrected for ash. Seamless cellulose dialyzer tubing, 0.00072-in. thick, was used for dialyses, which were against frequent changes of distilled water for at least 48 hr.

Sheets of Whatman no. 1 paper were used for chromatography, and were equilibrated and eluted by downward displacement in sealed tanks. The spray for detecting phenols consisted of water containing 0.2% each of ferric chloride and potassium ferricyanide (*21*); acids were detected with a bromphenol spray, but if the eluent contained formic or acetic acid the sheets had first to be very thoroughly dried at 105°C. The solvent systems used were the organic phases of the following mixtures by volume: (A) methyl isobutyl ketone–formic acid–water, 10:1:1; (B) hexane–dioxane–water, 6:3:1; (C) hexane–pyridine–water, 1:1:1; (D) butanol–acetic acid–water, 4:1:5; (E) butanol–2% aqueous ammonia; and (F) methyl isobutyl ketone–water, 10:1.

Formaldehyde-periodate Lignin

Previous directions (*5*) were followed, 40 g. of periodate lignin being allowed to swell for 12 hr. in 200 g. of 37% commercial formalin before 600 g. of 88.5% sulfuric acid was very slowly added with stirring. Solid carbon dioxide was simultaneously added to keep the temperature below 41°C., and thereby to avoid a high ash and sulfur content in the product. The black, gummy mixture was worked at 41 to 42°C. with a glass rod for 40 to 50 min., and the resulting dark viscous solution was then chilled and slowly poured into 1600 ml. of ice and water. After the precipitate of formaldehyde lignin had been well washed with very dilute sulfuric acid, the suspension was adjusted to pH 8 to 9 with *N* NaOH and the resulting dark-brown solution was filtered through sintered glass. The product was precipitated by acidifying the filtrate to pH 2, and after recovery in a wet condition was redissolved in acetone. This solution was centrifuged to remove inorganic material, was diluted with 200 ml. of water, and concentrated to remove the acetone. The remaining aqueous suspension was adjusted to pH 6 and the product was isolated as a brown powder by freeze-drying.

Yield: 41.8 g. Found: OCH_3, 9.5; S, 1.5; ash, 5.3%.

Formaldehyde lignin was soluble in aqueous sodium bicarbonate and in acetone, methanol, or ethanol containing a little water, but was insoluble in chloroform, benzene, or dilute sulfuric acid. These solubilities were sometimes, but not always, lost when the lignin was stored.

Oxidations with Nitrobenzene and with Cupric Hydroxide

Mixtures of the formaldehyde lignin, 0.05 g., 4 *N* NaOH, 1 ml., and either 0.3 g. of cupric hydroxide (*5*, *22*) or 1 ml. of benzaldehyde (*23*) were heated at

175°C. for 3 hr. Oxidation with cupric hydroxide was more convenient because the acidified liquor could be spotted without further processing on paper chromatograms. The chromatograms were developed with solvent E (*22*), which readily recorded vanillin, R_f 0.57, in parallel oxidations of periodate lignin. The absence of any spots on the chromatograms from the oxidized formaldehyde lignin showed that no detectable amount of the periodate lignin had escaped condensation with the formaldehyde.

Oxidations with Iodic Acid

The wet-combustion procedure of Kleinert and Wincor (*24*) was recently shown to oxidize the higher benzenepolycarboxylic acids completely at more than 200°C. (*25*); below this temperature these acids were almost unaffected (*5*). The previous modification (*5*) was adapted to a semimicro scale employing 0.1 g. of formaldehyde lignin and 1 ml. of conc. H_2SO_4 saturated with potassium iodate. Reagents added later were in the proportions previously used, and the temperature was maintained within the limits 180 to 200°C. After the dilution with water and the expulsion of iodine by boiling, the material extracted from the aqueous liquor by ether was redissolved in water and spotted on chromatograph paper, which was developed with solvent A for 12 hr. In oxidations of periodate lignin, the bromphenol blue spray revealed two spots, R_f 0.12 and R_f 0.30, corresponding to benzenepentacarboxylic acid and to the 1,2,4,5-tetracarboxylic acid, respectively. Formaldehyde lignin, and all fractions and derivatives thereof which were examined, when oxidized never yielded the spot of R_f 0.30, although that of R_f 0.12 was strong. A spot of R_f 0.01, presumably that of mellitic acid, was also apparent.

Oxidations with Alkaline Potassium Permanganate

Previous methods (*5*, *7*) were followed, a 9-g. sample of formaldehyde lignin in 1% potassium hydroxide being thoroughly oxidized near 80°C. for 80 hr. by the gradual addition of 70 g. of powdered potassium permanganate. The product was recovered as a mixture of barium salts which included barium sulfate derived from the 1.5% of sulfur in the formaldehyde lignin. After the elimination of the sulfate, the free acids from the remaining barium salts were isolated and some crystalline oxalic acid dihydrate, m.p. 101°C., was separated. The residual free acids were boiled in concentrated nitric acid to eliminate any oxalic acid or other keto acids, and the benzenepolycarboxylic acids were isolated as a crystalline mixture. The results of a parallel oxidation of periodate lignin were included in Table II.

Column Chromatography of Benzenepolycarboxylic Acids

Preliminary experiments showed that a known mixture of mellitic acid and benzenepentacarboxylic acid was not eluted from a "Dowex 1-4X" (acetate form) anion-exchange column by 2 *N* acetic acid; both components of the mixture were removed simultaneously by 0.1 *N* to *N* trifluoroacetic acid. When a cellulose column was used, 5% aqueous formic acid eluted both components simultaneously, and the separation caused by solvent A was ill defined. A mixture of methyl isobutyl ketone–water (solvent F), prepared by omitting the formic acid from solvent A, failed to elute mellitic acid but removed benzene penta- and 1,2,4,5-tetracarboxylic acids as separate fractions.

Table II. Oxidations with Alkaline Permanganate

Products	*From formaldehyde lignin*[a]	*From periodate lignin*[b]
(a) Crude barium salts	6.75	6.24
(b) Ba salts insoluble in aqueous HCl ($BaSO_4$)	1.30	0.04
(c) Oxalic acid dihydrate from (a)	0.55	1.06
(d) Residual acids from (a)	1.02	0.95
(e) Residual acids (d) after oxidation with HNO_3 (benzenepolycarboxylic acids)	0.44 (4.9%)	0.41 (4.1%)

[a] From oxidation of a 9-g. sample.
[b] From oxidation of a 10-g. sample.

The residual acids, 0.39 g., from the oxidation of formaldehyde lignin (Table II) were dissolved in a little of solvent F and were added to the top of a 15 by 2 cm. column of powdered cellulose made up from a slurry in the same solvent. Elution was at the rate of 5 ml. per min., and alternate 100-ml. fractions were chromatographed on paper with solvent A. After the spot of R_f 0.12 ceased to appear (2 liters of effluent) elution was continued with 100 ml. of 5% aqueous formic acid. The solvent F effluents containing benzenepentacarboxylic acid on evaporation yielded a slightly brown product which gave pure material, m.p. 235°C., when recrystallized from hot concentrated nitric acid. Yield: 0.27 g. or 3.5%. Mellitic acid isolated from the formic acid effluent and recrystallized from nitric acid melted correctly at 284°C. Yield: 0.093 g., or 1.2%.

The same chromatographic process was applied to 0.37 g. of the residual acids from the oxidation of periodate lignin (Table II). No mellitic acid was isolated, but 0.26 g. (2.9%) of the pure pentacarboxylic acid and 0.074 g. (0.8%) of pure benzene-1,2,4,5-tetracarboxylic acid were recovered.

Methanolysis and Extractions with Methanol (Fig. 2)

Thirty grams of formaldehyde lignin was boiled under reflux three times with 1 liter volumes of anhydrous methanol, each extraction lasting 30 min. The first extract was red, and the third, pale yellow. The undissolved residue was recovered on fritted glass, was repeatedly washed with water, and dried.

Yield: 70%. Found: OCH_3, 10.5; S, 1.65; ash, 6.8%.

The combined extracts were evaporated to 50 ml., latterly with the addition of water to expel the methanol, and were freeze-dried.

Yield: 24%. Found: OCH_3, 7.9; S, 1.5; ash, 6.7%.

A calculation by the method of mixtures showed that the average methoxyl content of the soluble and insoluble fractions was 9.8%, in fair agreement with the value for the original formaldehyde lignin.

A solution of the soluble fraction, 0.2 g., in 50 ml. of distilled water was dialyzed for 48 hr.

Yield: 0.16 g. nondialyzed and 0.04 g. dialyzed, or 19% and 5%, respectively, of the original lignin.

Another 0.2-g. sample was boiled under reflux for 1 hr.

with 2% methanolic hydrogen chloride; the solution was neutralized with 5% aqueous sodium bicarbonate, and the concentrated filtrate was stirred into 5 volumes of water (*26*). Next day, the brown precipitate of the methanol lignin was thoroughly washed with water and dried.

Yield: 0.138 g., or 15.5% of the lignin. Found: OCH_3, 14.7; ash, 3.2%.

Dialysis of the concentrated liquors left only 0.034 g. of nondialyzable material (4.3%), and the dialyzable portion was 4.4% by difference. A parallel methanolysis was continued for 48 hr. instead of 1 hr. but the results almost exactly duplicated those just given. Paper chromatograms of the fractions soluble and insoluble in water revealed faint spots of R_f 0.73 to 0.76 in solvents B and C, and major spots at or near the starting line in solvents B, C, D, and E. The original formaldehyde lignin was also boiled under reflux with 20 volumes of 2% methanolic hydrogen chloride for 6 hr., when the deep-brown extract was replaced by fresh reagent. After the fourth extract, which was yellow, had been removed the residue and liquors were processed as already described. The yield of the water-soluble fraction (Fig. 2) was determined by difference.

Attempted Sulfonations (Fig. 2)

Following published directions for the sulfonation of periodate lignin (*6*), 0.4 g. of the formaldehyde lignin and 20 ml. of 16% aqueous sodium sulfite were mechanically stirred at 97°C. and pH 4.8 to 5.2 for 20 hr.

The fraction remaining in suspension was recovered as a light-brown gel swollen to 5 or 6 times the original volume, but this gel collapsed when washed free of excess sodium bisulfite with water.

Yield: 44%. Found: S, 1.6; ash, 6.3%.

This product was swollen and then heated at 98°C. for 24 hr. at pH 2 in a potassium chloride–hydrochloric acid buffer. After recovery, the undissolved portion amounted to 38% of the formaldehyde lignin, and its composition was unchanged.

Found: S, 1.6; ash, 6.9%.

The bisulfite liquor and washings yielded 35% of the lignin as a nondialyzable fraction, and, by difference, the dialyzable portion was 21%.

The fractions of formaldehyde lignin soluble and insoluble in neutral methanol were separately treated with sodium bisulfite as just described, with the results noted in Fig. 2. The dialyzable portion of the product from the soluble fraction, and also the nondialyzable product after acid hydrolysis, were chromatographed on paper with solvent C. Both gave spots at the solvent front. With this exception, all the products from bisulfite cooks gave spots only at the starting line with all four solvents B, C, D, E.

In the main experiment, 40 g. of formaldehyde lignin was heated at pH 5 and 98°C. for 1 hr. with 800 ml. of 1% aqueous sodium bisulfite. The resulting black liquor was dialyzed and both fractions were concentrated to suitable volumes and freeze-dried.

Yield of the nondialyzable fraction A: 34 g. or 85%. Found: OCH_3, 10.1; S, 1.0; ash, 3.7%.

One gram of this fraction was de-ashed by cold 2*N* HCl, washed free of chloride ion, and autohydrolyzed in water at pH 2 and 100°C. for 2 hr. The resulting yellow slurry yielded 0.77 g. of insoluble, and 0.075 g. of soluble, material, none of which was dialyzable. Autohydrolysis for 24 hr, did not alter the result.

After being freeze-dried as noted above, the dialyzable product contained 54% of ash.

Yield, corrected for ash: 5.4 g. or 13.5%.

Extraction of 1 g. with methanol yielded 0.5 g. of soluble material.

Found: OCH_3, 13.0; S, 6.3; ash, 21.5%.

Products of reduced ash content were not obtained by extractions with acetone, dioxane, or tetrahydrofuran. A 0.2-g. sample was passed in aqueous solution through a column of "Amberlite IR-120" cation-exchange resin, the acidic effluent was concentrated to expel any sulfur dioxide, was neutralized with caustic soda, and freeze-dried.

Yield: 0.16 g. Found: S, 6.1; ash, 20.7%.

A duplicate sample was made alkaline to pH 8.5 with aqueous barium hydroxide and kept overnight to precipitate any sulfate ion, the filtrate then being decationized and processed as before.

Yield: 0.15 g. Found: S, 5.8; ash, 18.2%.

Freeze-drying of unneutralized, acidic effluents rendered about one-fourth of the products nondialyzable either at pH 2 or pH 5, although they were still completely soluble in water; autohydrolysis caused about one fourth to become insoluble.

The experiments on the sulfonation of formaldehyde lignin were repeated with citric acid–disodium phosphate and acetic acid–sodium acetate buffers at pH 5 instead of with sodium bisulfite. The former buffer dissolved 20% of the lignin, and the latter 25%, or 50% if 1% of sodium bisulfite was also added. In all three cases the dialyzable portion remained within the limits 9 to 11%.

Degradation with Sodium Azide (Table I)

The directions of Schuerch (*13*) were adapted to a smaller scale involving 2 g. of dry, finely divided formaldehyde lignin fraction A, 8 ml. of concentrated sulfuric acid kept near 0°C., and 0.9 g. of sodium azide. After 45 min., the mixture was cautiously diluted with 20 ml. of cold water, the product was recovered on sintered glass, was well washed with water and dried.

Yield: 6 g. of a black gum that was insoluble in all the organic liquids tried.

Extraction of this gum with cold *N* NaOH left 1.4 g. of a black residue.

Found: OCH_3, 7.4; S, 4.0; N, 4.1%.

The alkaline extract was dialyzed against distilled water and the nondialyzed portion, 0.1 g., was isolated as a brown powder.

Found: OCH_3, 21.4; S, 7.1; N, 3.6%.

By difference, about 0.5 g. of the lignin was dialyzable.

A repetition of the experiment with periodate lignin yielded 2.68 g. of a black gum, of which 0.88 g. failed to dissolve in the alkali.

Found: OCH_3, 10.5; S, 4.7; N, 2.9%.

The wine-red alkaline extract yielded 0.54 g. of non-dialyzable brown resin.

Found: OCH_3, 12.5; S, 5.7; N, 2.3%.

In this case, about 0.58 g. was lost by dialysis.

Degradation with Boron Trifluoride (Table I)

The directions of Francis and Rudloff (*14*) were followed, 0.2 g. of dry, finely divided formaldehyde lignin fraction A being heated for 2 hr. at 122°C. in 4 ml. of acetic anhydride saturated with boron trifluoride at less than 60°C. The mixture was then poured into cold, aqueous sodium bicarbonate; 0.4 g. of a black precipitate was recovered, washed with benzene, and dried. All but 0.01 g. dissolved in water, and both the dialyzable and nondialyzable products were recovered by freeze-drying.

Yields: 0.138 and 0.26 g., respectively. Found for the dialyzable portion: OCH_3, 15.4; ash, 51%. Found for the nondialyzable portion: OCH_3, 5.4; ash, 7.0%.

The reaction was repeated with 0.2 g. samples of periodate lignin for various temperatures and times, but the initial black products were dissolved in chloroform instead of water. These solutions were washed with water, and dried over anhydrous calcium chloride. The yields of dark gums from reactions at 25, 50, 75, 100, and 122°C. (reflux) were 100, 104, 110, 120, 130% by weight, respectively, and were not greatly altered when the reaction time was extended from 1 hr. to 4 hr. Blank experiments in which the lignin was omitted showed that the yellow reaction mixture became black when treated to 122°C., and yielded up to 0.09 g. of dark, nondialyzable material that responded negatively in a determination of methoxyl groups.

Degradation with Aluminum Tribromide (Table I)

One gram of the formaldehyde lignin fraction A was boiled under reflux for 3 hr. with 50 ml. of an 8% solution of aluminum bromide in benzene (*16*). The suspension was then cooled, diluted with 20 ml. of water, and 50 ml. of hexane was added to facilitate the removal of the water layer. The hexane-benzene liquor contained no material of interest. The aqueous suspension was filtered, the residue was washed with water, then with benzene, and dried.

Yield: 1.12 gram. Found: OCH_3, 5.3; Br, 0.03; ash, 2.7%.

Practically the same yield, with the same methoxyl content, was obtained when aluminum bromide in chlorobenzene or in benzene-nitromethane (1:1 v/v) was used. Extraction of this product with cold *N* NaOH left 0.75 g. undissolved; purification of this fraction consisted of repeated washing with water.

Found: OCH_3, 6.2; Br, 0.03; ash, 8.6%.

The brown alkaline extract plus the washings yielded 0.18 g. of a nondialyzable powder.

Found: OCH_3, 6.1; Br, 0.0; ash, 3.7%.

One gram of periodate lignin was boiled with aluminium bromide in benzene as just described, and the undissolved product, 0.98 g., was dried.

Found: OCH_3, 11.2; Br, 0.03; ash, 0.8%.

Extraction of this product with *N* NaOH left a residue, 0.70 g.

Found: OCH_3, 11.0; Br, 0.04; ash, 2.5%.

The alkaline extract yielded 0.15 g. of nondialyzable material.

Found: OCH_3, 11.7; Br, 0.01; ash, 1.1%.

Aluminum bromide, 3.64 g., in 50 ml. of boiling benzene was used for 3 hr. to demethylate 0.7 g. of *p*-dimethoxybenzene. In this case, the organic layer (hexane–benzene) was twice extracted with 10 ml. volumes of 20% NaOH which was then strongly acidified and re-extracted with ether. The ether extract gave a 50% yield of hydroquinone with the correct m.p. 168 to 170°C., not depressed by mixture with an authentic sample. Under the same conditions, vanillin, 0.5 g., and aluminum bromide, 2 g., yielded 60% of unchanged vanillin with the correct methoxyl content and mixed m.p. (79°C.). Demethylations attempted at room temperature for up to 24 hr. gave the same result.

Degradations with Hydriodic Acid (Table I)

Finely divided formaldehyde lignin fraction A, 25 g., and 500 ml. of 47% hydriodic acid were heated together for 8 hr. at 50°C. in a 1-liter, 3-neck flask equipped with a mechanical stirrer, a condenser and thermometer (*20*). The suspension was then cooled, diluted with 500 ml. of water, and filtered through sintered glass. After any free iodine had been extracted with 5% aqueous potassium iodide, the brown residue was thoroughly washed with water and dried.

Yield: 23 g. Found: OCH_3, 9.1; I, 0.3; ash, 1.2%.

The wine-red filtrate and washings were dialyzed, and 1 g. of a brown, nondialyzable material was isolated by freeze-drying.

Found: OCH_3, 3.3; I, 0.4; ash, 1.2%.

The insoluble residue, now resistant to the hydriodic acid, was extracted with 460 ml. of cold, *N* NaOH. A dark-brown powder remained which was washed free of alkali, and dried.

Yield: 17.7 g. Found: OCH_3, 9.4; I, 0.1; ash, 8.5%.

The dark-red, alkaline extract and washings were neutralized to pH 7 with *N* H_2SO_4, and after concentration, sodium sulfate was precipitated from the yellow liquor by adding 2 volumes of ethanol. After further concentration, the mother liquor was dialyzed, the nondialzyable product being isolated by freeze-drying as a yellow-brown powder.

Yield: 2 g. Found: OCH_3, 8 6; I, 0.25; ash, 3.7%.

The dialyzate was concentrated to about 125 ml. at pH 7.5, and was freeze-dried.

Yield: 3.5 g. of a yellow-brown gum.

This gum yielded a blue spot of R_f 0.26 when chromatographed on paper with solvent E and the ferric chloride–potassium ferricyanide spray; when ammoniacal silver nitrate was the spray, a brown-violet spot of R_f 0.25 appeared. Development for 15 to 20 hr. with a water–ligroin–chloroform–methanol mixture (5:7:2:1) known to be suitable for some lignin precursors (*27*, *28*), or with a ligroin, *n*-butyl ether–water

(6:1:1 v/v) mixture (*23*), failed to move the sample from the starting line. A solution of the sample, 3.5 g. in 50 ml. of solvent E, was finally chromatographed on a 1.8 by 50 cm. column of powdered cellulose with the same solvent system as eluent, 25 ml. fractions being collected. Fractions 9 to 24 contained 2.5 g. of the clear yellow gum of R_f 0.26; fractions 25 to 80 yielded 0.38 g. of other material of indefinite R_f, and later fractions, 0.25 g. of a yellow oil that stayed near the starting line when chromatographed on paper.

The major product, of R_f 0.26, soon crystallized in part, but all attempts to separate the two components by solvent extraction proved fruitless. The mixture was soluble in water, alcohol, dioxane, and pyridine; was sparingly soluble in acetone and ethyl acetate but insoluble in ether, chloroform, benzene, carbon disulfide, and carbon tetrachloride. Single spots of R_f 0.21 or 0.88 were obtained when the mixture was chromatographed on paper with solvents C or D, respectively, as eluents. The ultraviolet absorption spectrum of the mixture in 0.005% aqueous solution revealed the maxima near 200 mμ and 280 mμ characteristic of most lignin preparations. The corresponding infrared absorption spectrum was determined on a recording Perkins Elmer spectrometer Model 21, using a sodium chloride plate. Marked absorption in the frequency range 3200 to 3600 cm.$^{-1}$ indicated the presence of phenolic groups, in accord with the red color observed when the sample was tested with ferric chloride solution.

CONCLUSIONS

The methods explored in the above research degraded not more than one-third of the periodate and formaldehyde lignins to a dialzyable condition, and not more than one-tenth to a state that was mobile on paper chromatograms. Failure to degrade the remaining two-thirds of the lignin strengthened the supposition that this portion was united by very stable diphenyl ether links or by carbon-carbon bonds. Methods of cleaving such bonds without simultaneously promoting autocondensation of the lignin still remain to be discovered.

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Moisture and Temperature Distributions During Drying of Insulation Board

KENNETH O. JOHNSON

Distribution of moisture during drying has previously been determined for paper but not for insulation board. Since this information is necessary for a fundamental understanding of the drying process, and since the properties of and drying practice for insulation board are considerably different from those for paper, the distribution was determined at various stages of drying at 155 and 205°C. This was accomplished by slicing samples of board into 1-mm. thick pieces parallel to the surface and measuring the moisture content of each piece. It was found that approximately 90% of the evaporation occurs in a very thin zone. This zone is at the surface for a very short time and then recedes into the board, finally reaching the center when the total board moisture is less than 10%. The removal of bound water occurs practically continuously, starting near the surface after only 20 min. and follows the major evaporation zone as it proceeds inward. By the time that only bound moisture remains the board is already as dry (approx. 5%) as is normally desired. During most of the drying process there is a surface layer of 2 to 4% moisture content, a 1 to 2 mm. thick region in which most of the moisture content increase occurs and a wet center section, the moisture content of which falls slowly throughout the process. Liquid water can diffuse only a short distance in the time available, but water vapor diffuses very readily through the board. At the higher temperature, and thus

the higher drying rate, the moisture gradient is steeper and the evaporation zone moves inward relatively sooner than at the lower one. The use of dielectric heating, however, decreases the gradient. Temperatures during air-drying are uniform throughout the wet zone but increase sharply in the evaporation zone. Dielectric heating and low temperature radiant heating hold promise of increasing the drying rate economically, but high air velocity drying holds little promise for insulation board.

ALTHOUGH the moisture distribution during the drying of paper has been determined, it has not been reported for insulation board. An approximate determination was made by Carter (*1*), but the only use made of those data was to demonstrate that dielectric heating could be used for final board drying without overdrying the surface, something which is not possible with conventional drying systems. It seems, however, that knowledge of moisture distribution is necessary to a basic understanding of insulation board drying. McCready (*2*, *3*, *4*) published information on the drying of thick paper pads, in 1932. His curves for the moisture distribution during air-drying of paper became more and more similar to the curves reported here as he went through the series parchment, bond, and blotting paper. Presumably, if he had extended the series to coarser fibered, more porous pads he would have obtained curves identical to the ones reported here. Instead, he directed his later attention to drying on hot surfaces such as is commercially practiced with paper.

A more recent study of the mechanism of air-drying of paper was made by Higgins (*5*). Because he worked with thin sheets (0.025 cm.) and low temperature (of the order of 40°C.) his distributions are entirely different from those found for insulation board. He concluded, "Thus it appears that all of the 'free water' and possibly some of the 'bound water' in the sheet was able to move to the surface at a rate sufficient to maintain the surface evaporation rate at its maximum value." An entirely different situation obtains in insulation board, since the corresponding period does not last for a measurable time for insulation board as dried commercially.

Most of the work on paper is devoted to hot surface drying, as reported recently by Nissan and Kaye (*6*), and by Dreshfield and Han (*7*). The conditions and results are so different as to have practically no application to insulation board drying.

The basic literature dealing with the drying of insulation board is limited. Lund (*8*) reported the results of his experiments on the drying of one of the insulation boards made by the Minnesota and Ontario Paper Co. as a function of temperature, air velocity, and humidity. Further work was done by several authors (*1*, *9–15*). Most of these papers either do not contain information on moisture distribution or make some general comments based on the drying theory that have only an approximate application. An example of general drying theory is that by Badger and McCabe (*16*), and later McCabe and Smith (*17*), who divide the drying of hygroscopic materials into four periods: (1) constant rate, (2) first falling rate, (3) second falling rate, and (4) bound-water removal. However, Dalley (*12*) found that under the conditions now commonly used, the constant rate period is totally lacking and the first falling-rate period is relatively short. The second falling-rate period is the most important one, with bound-water removal dominating only below 12% total moisture content. The work reported here indicates that the second falling-rate period is an even larger share of the total drying time, amounting to about 80% at 155°C. and an even higher percentage as the temperature is increased. There is no separate bound-water removal step as the board is dried commercially, because free water persists in the center to near the very end of the drying period.

In previous studies (except the work by Carter) samples were weighed periodically during drying and then total-moisture-content versus time relationships calculated. The data obtained agreed fairly well with general drying theory but did not indicate very accurately when each period of drying was occurring, and still less did it indicate the probable moisture distribution. Even the special ovens generally constructed did not solve the problem. The estimations that were made did not agree well with direct observation of board during drying. In particular, the surfaces were drier and the centers wetter than predicted. Therefore, it was decided to determine the moisture distribution directly. The moisture distribution and the related temperature distribution during drying are important to the development of sizing and dried-in strains. They are also of importance in calculating the effect of changes in drying conditions. A better understanding of these distributions might also point the way toward faster or more efficient drying, or both.

EXPERIMENTAL TECHNIQUE

Insulation board wet lap, sampled following wet pressing, was obtained from regular production. Board made from coarse groundwood with only minor amounts of additives such as for sizing, and of nominal caliper of $1^1/_4$ cm. ($^1/_2$ in.) was used throughout these experiments. The dry density of the board was 0.28 g. per cc. (17 lb. per cu. ft.). Moisture content of the lap varied from 162% (oven-dry basis) to 186%, and finally down to 144% over the period during which the work was performed, as changes were made in the process.

A Model 18 oven (Precision Scientific Co., Chicago, Ill.), was used in the experiments reported here. In the first major series, samples of approximately 1500 sq. cm. total area were placed in the preheated oven simultaneously, and dried at 155°C. This provided sufficient material to determine average moisture content, temperature, and moisture distributions, and also provided the desired humidity. When the samples had been in the oven for the desired length of time they were removed and one sample was trimmed to eliminate the effect of edge drying. It was then sliced parallel to its face into 12 to 14 slices with a Model 11 cold meat slicer (Hobard Mfg. Co., Troy, Ohio). As each slice was made the resulting piece was immediately placed in a glass-stoppered weighing bottle. Weight loss during slicing, not due to the visible loss

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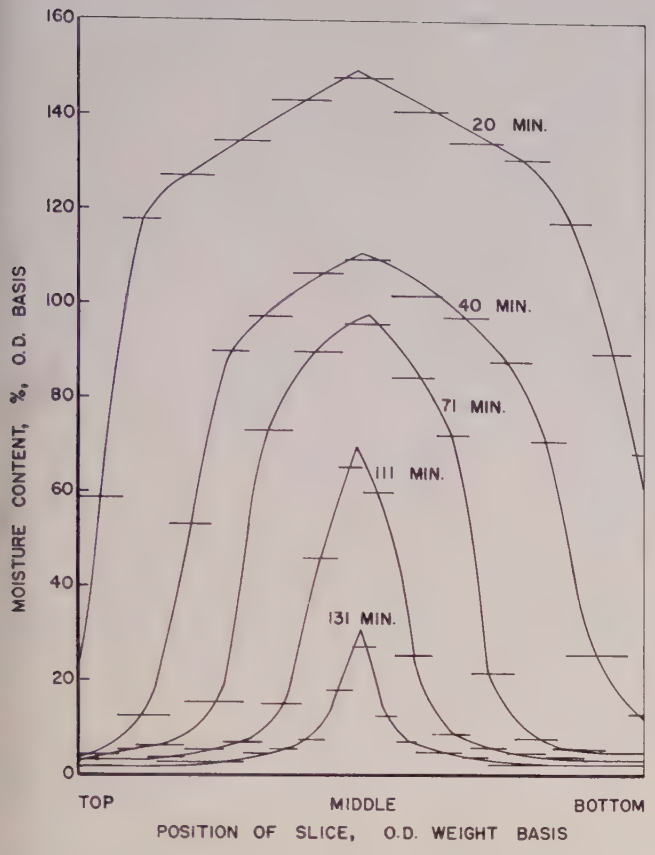

Fig. 1. Moisture distribution within insulation board after various periods of drying at 155°C. in the laboratory oven

of pieces, was determined to be only 1 to 2%, showing that no significant amount of water was lost during that time. In some cases the slices were made of unequal thicknesses to get greater resolution in a region of rapid change. The operation, from removal from the oven to placing the last slice in the bottle, normally took less than 1 min. Moisture content was always based on the weight after drying, to constant weight at 105°C.

During later experiments, only one small sample

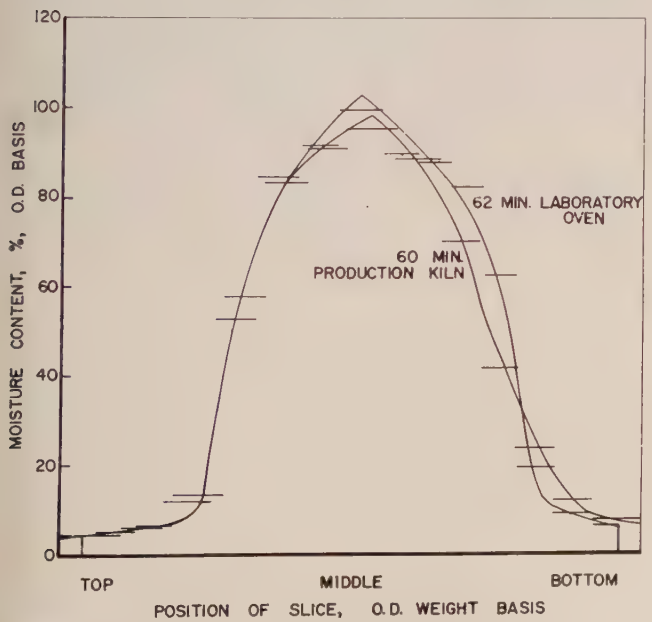

Fig. 2. Comparison of the moisture distributions within boards dried in the production kiln and at 155°C. in the laboratory oven

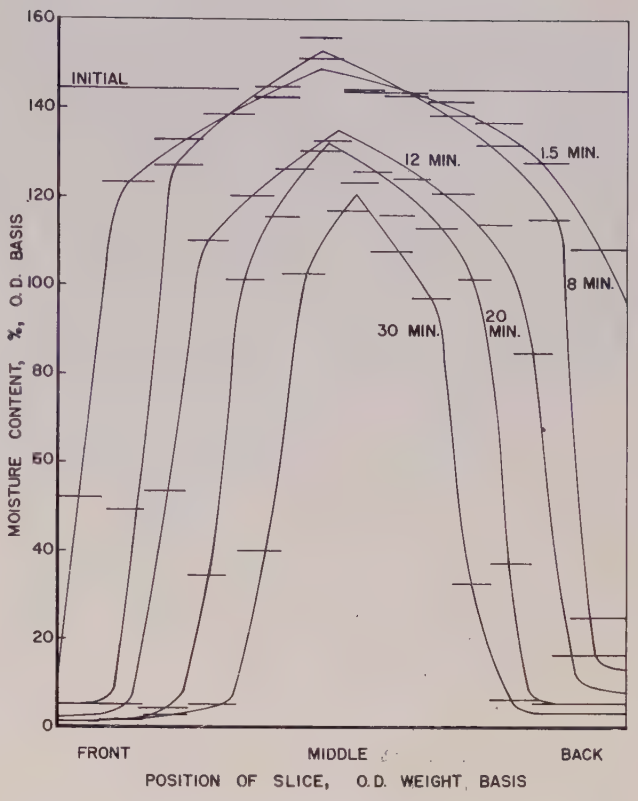

Fig. 3. Moisture distribution within insulation board after various periods of drying at 205°C. in the laboratory oven with a 5-m-per-sec. (1,000 f.p.m.) stream of air directed at the "front" side of the sample

was in the oven at one time. The oven itself supplied very low air velocities; hence, for some of the fast drying runs an additional fan was used that directed a stream of air against one surface.

A 195X Thermex unit (Girdler Process Equipment Division of Chemtron Corp., Louisville, Ky.) was used to supply dielectric heat for short periods to hasten drying, and to learn how an entirely different method of supplying energy would affect the moisture distribution.

Temperatures were determined by imbedding 24 gage iron-constantan thermocouples in wet lap samples at various points and reading them with a Model 8658F potentiometer (Leeds & Northrup Co., Philadelphia, Pa.)

RESULTS

Moisture Degradation and Migration

The results of the moisture distribution determinations are shown graphically. The moisture content of the slices and their relative size and position in the board, based on dry weight, are shown by short horizontal lines.

The best estimates of the moisture content at each point in the board are shown by the curves. They are the best smooth curves that can be drawn such that approximately equal areas are included under the curve and under the corresponding horizontal line.

Figure 1 shows the distribution of moisture during drying under conditions intended to simulate production conditions. The left-hand edge is the upper surface in the oven in this and the other graphs, except in Fig. 3 where the sample was standing on edge, toward the auxiliary fan. The upper surfaces dried

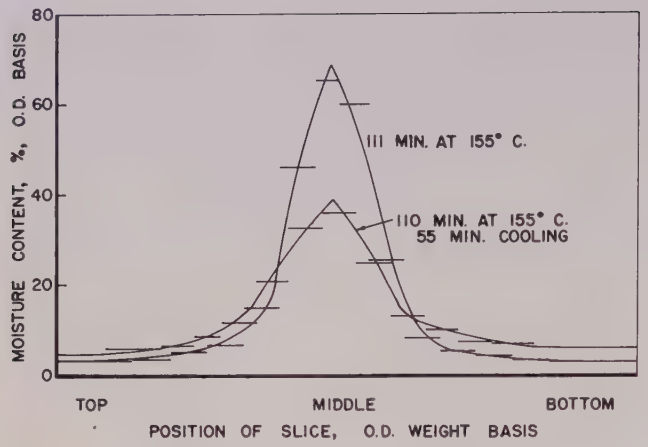

Fig. 4. Moisture distribution within partly dried insulation board before and after cooling for 55 min.

with the left-hand edge of the graph being the surface somewhat more rapidly, presumably because of greater air circulation. The exact shape of these curves at the center and at places of rapid change can only be estimated, since the thickness of the sample (approximately 1 mm.) limits the resolution.

The attempt to duplicate kiln-drying results was very successful, as can be seen in Fig. 2, which shows the moisture profile found in a sample taken from a production kiln after 60 min. of drying and the profile in a sample dried for 62 min. in the laboratory oven. It may be noted that the boards were not of exactly the same thickness but this would not significantly affect the comparison.

The moisture distribution in board dried 2 $^1/_2$ times faster than the board in Fig. 1 is shown in Fig. 3. The evaporation zone moves inward relatively sooner and the gradient is steeper. The layer of board between the evaporation zone and the surface is drier and the center is wetter at the same total moisture content than is the case in Fig. 1. Total drying time to 5% moisture at the higher rate was approximately 55 min.

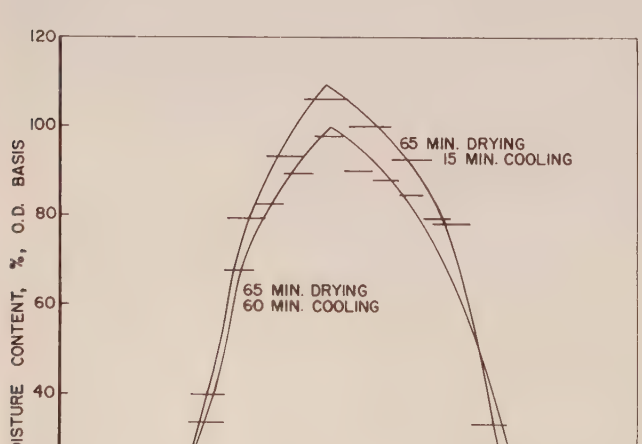

Fig. 5. Comparison of the moisture distribution within insulation board partly dried at 155° C. after cooling for 15 or 60 min.

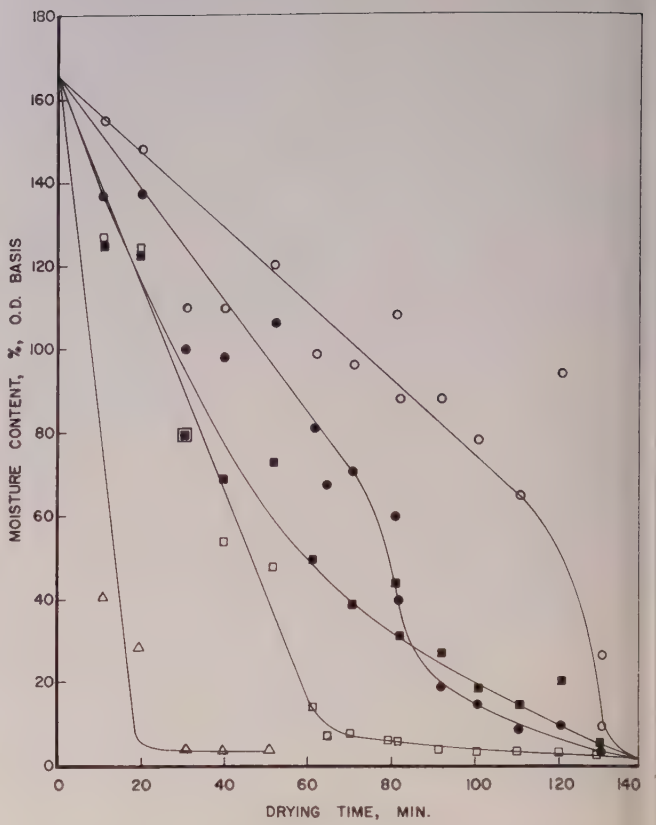

Fig. 6. Moisture content as a function of time at various positions within insulation board dried at 155° C.

○ center, ● $^2/_3$ of the distance from the board surface to its center; □ $^1/_3$ of the distance from the board surface to its center; △ surface of the board; ■ total moisture content of the board.

The water in the board does not migrate very far in the length of time available during drying. A few runs were made during which board was sliced as quickly as possible without trimming. These were followed by runs that were conducted in exactly the same way except that 3 min. extra time was allowed to pass before slicing. The moisture front had moved only 0.2 to 0.4 mm. during that time, indicating that generally this was not a very important factor. The only time that it might be important is when the dry layer is very thin and might largely disappear before slicing. Longer waiting periods were tried to make the movement more obvious. Figures 4 and 5 show the results of drying for and waiting for various periods of time. It can be seen that even with these longer times little movement has occurred. No 65-min. drying without cooling curve is available, but the 70-min. drying curve falls between the two curves of Fig. 5.

All of the moisture distribution curves, except those for board dried with dielectric heat, are very similar, showing that no change in mechanism has occurred over this range of drying rates, and that only a small change has occurred in the relative lengths of the various drying periods. The principal limiting factor in board drying is the rate at which heat can be transferred through the dry surface layers to the evaporation zone, especially after the early part of the drying cycle. Water does migrate a short distance toward the dry surfaces in the time involved but not far enough to be a major factor. The slowness of the migration is indicated by the very rapid increase in moisture con-

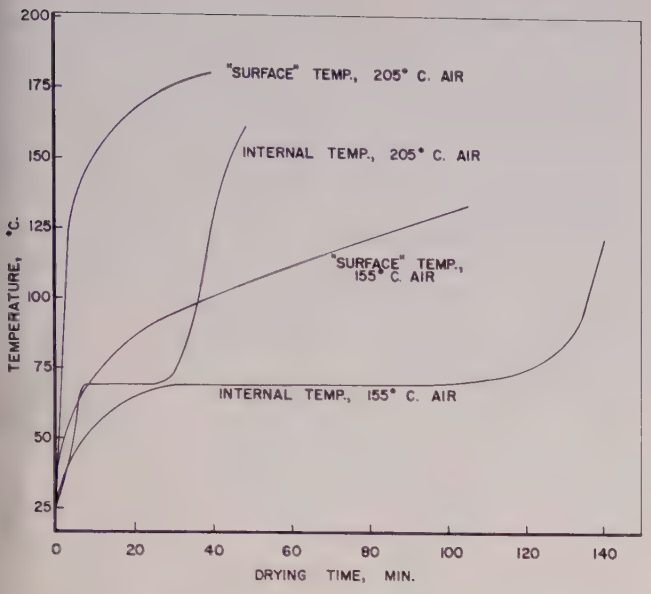

Fig. 7. "Surface" and internal temperatures of insulation board during drying at 155°C. without and 205°C. with a 5-m.-per-sec. (1,000 f.p.m.) stream of air directed against the surface

tent at the edge of the evaporation zone, and by the small movement that has occurred after waiting for various periods of time, as shown in Figs. 4 and 5.

Figure 6 shows the moisture content of various planes in the board and the total moisture content during the drying cycle. The curves are derived from the information in Fig. 1 and also include the points for all other runs made under the same conditions, though not included in Fig. 1. The moisture content near the surface drops rapidly below the fiber saturation point and then more slowly as the relative humidity at that particular place decreases. At positions farther from the surface, the moisture content drops slowly and uniformly for a time owing to the migration of water and then suddenly to below the fiber saturation point as the evaporation zone passes it. The process at the center is the same except that the moisture content is lower before the evaporation zone reaches it and then the moisture content falls at once to a lower value because there is no cool, wet inner zone any longer to absorb heat and prevent a substantial increase in temperature.

Temperature Distribution

The surface temperature, Fig. 7, rises rapidly during air-drying, and without pause to a value somewhat below air temperature. The lack of any pause indicates that there is no constant-rate period, since this would require the surface to remain at the wet bulb temperature of the air for the duration of the period. The temperature for the curve for drying at 205°C. with the auxiliary fan quickly exceeds 100°C. This shows that the first falling-rate period is very short, since it is over when the surface is dry, which must be the case before the surface can exceed the boiling point of water. The curve for drying at 155°C. does not exceed 100°C. for some time, and does not approach the air temperature as closely; but the similarity of the moisture distributions, as shown in Figs. 1 and 3, indicates that the drying mechanism is essentially the same.

The internal temperatures at various points within the board rise much more slowly and then remain at almost constant value until the evaporation zone reaches a given place. When several thermocouples are placed in the same board, all those within the wet zone read identically and rise in the order of their nearness to the surface.

Early in the drying cycle the internal temperature is undoubtedly below the dew point of the air near the surface. This being the case, it would be expected that some of the water evaporated near the surface could be condensed farther inside the board. Figure 3 demonstrates that this actually happens, since the moisture content at the center rises during the first few minutes of drying.

Of course, determining the "true" surface temperature is not possible with a thermocouple because of the large temperature gradient in the region. The finer the thermocouple and the more precisely it is placed at the surface, the more accurate will be the reading. There is even some difficulty in deciding just what constitutes the surface of the board, because on a microscale it is neither continuous nor smooth.

Water Vapor Migration

Insulation board of density 0.28 g. per cc. (17 lb. cu. ft.) is quite porous. Its maximum permissible drying rate is not limited by vapor transmission. For instance, high-speed drying performed in a few minutes by radio frequency electrical heating does not rupture the board.

One measure of the porosity is the diffusion rate of water vapor (or air) through the board as compared to the diffusion rate in free air. The diffusion rate was calculated to be one-third to one-half as great in board as in air, which shows that the air passages are extensively interconnected. Therefore, the total pressure inside the board cannot significantly exceed atmospheric pressure and the internal temperature cannot significantly exceed 100°C. while it contains free water. Actually, with the drying rates and air humidities used in this study, the temperature did not significantly exceed 70°C. where free water was present.

Case Hardening

It had been feared that increased drying rates especially early in the drying cycle would lead to the formation of a well-sized dry layer on the surface, which might be strained or even ruptured and which might hinder further drying to the point that the overall drying rate would be decreased. It can be seen that such problems are unlikely with the increase used here, not because such a layer would not form, but because it must be present in board as presently dried and would probably not be greatly increased. One trial was made, Fig. 8, in which 3 min. of drying at 205°C. with the auxiliary fan was followed by 17 min. at 155°C. The lower temperature gave the same rate as is presently used in the Minnesota and Ontario Paper Co. mill, whereas the higher one produced a drying rate $2^1/_2$ times greater. The degree of drying accomplished was more, rather than less, than predicted by combining the appropriate curves from Figs. 1 and 3. The resulting curve is like the curve for the same total moisture content in Fig. 1,

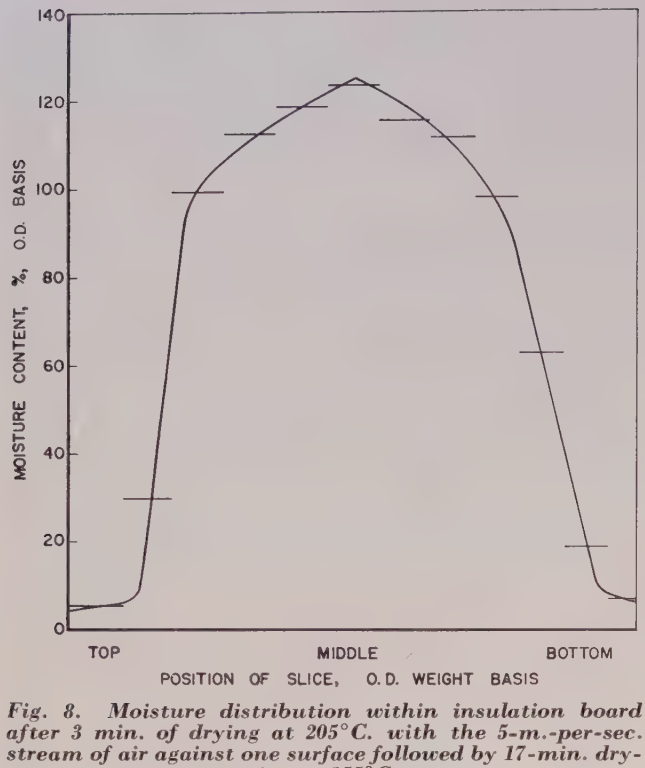

Fig. 8. Moisture distribution within insulation board after 3 min. of drying at 205°C. with the 5-m.-per-sec. stream of air against one surface followed by 17-min. drying at 155°C.

though the center is a little wetter, the surface drier, and the gradient steeper than in Fig. 1. These changes are characteristic of higher drying rates, since the water has less time to migrate.

Several methods that are substantially different from past insulation board drying practice have been proposed. Partial evaluation of their feasibility can be made on the basis of the data presented above.

Radiant Heating

The use of radiant heating is promising. It is already a factor in normal production where steam coils at 180°C. would account for a significant fraction of the heat transfer. Smith (*15*) reports the use of low temperature radiant heating. It is desirable that the radiators not be above approximately 250°C., especially after the first few minutes, if scorching is to be avoided. High temperature radiant heating offers no special advantage in insulation board drying, although the higher heat transfer per unit area can be used advantageously with paper board (*18*).

Radiant heating was not an important factor in this study because the interior of the oven was made of bright stainless steel, which has poor radiating efficiency.

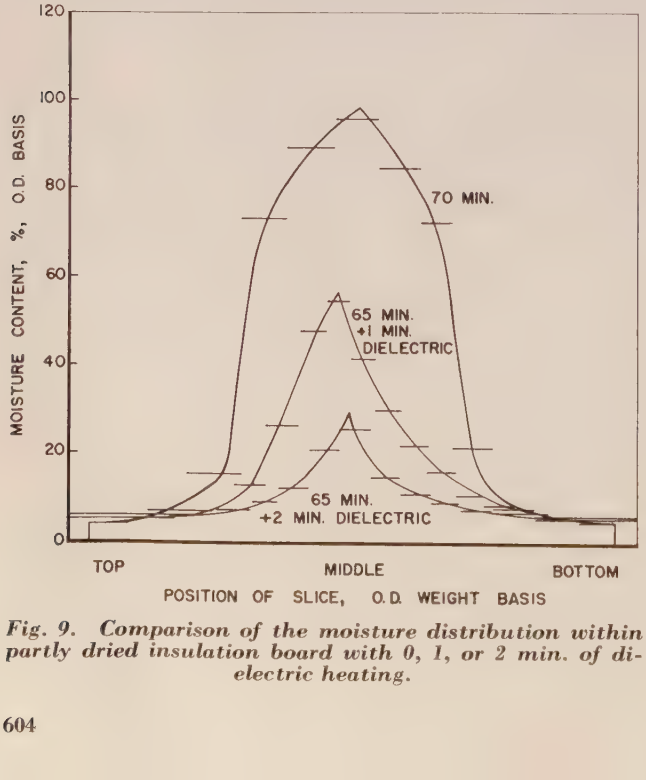

Fig. 9. Comparison of the moisture distribution within partly dried insulation board with 0, 1, or 2 min. of dielectric heating.

High Velocity Air Drying

High velocity air drying has been used to advantage in the drying of paper. However, in the case of relatively thick insulation board it would appear to offer little advantage after the first few minutes of drying, when the evaporation zone has shifted to the interior of the board. Data from this study show that the board surface can be raised to its maximum permissible temperature without the large expenditure necessary to move air rapidly.

Dielectric Heating

Dielectric heating can be used to greatly increase the drying rate, and thus the capacity of existing kilns, without the need for increased space, especially when it is used in the latter part of the drying period, when normal drying is slow. Since this is a fundamentally different way of transferring energy, it is not surprising that different moisture profiles result as shown in Fig. 9. The curves do not have a concave downward section as is usual in conventional drying, and the moisture content at the center is lower at the same total moisture content than is otherwise the case. Its usefulness lies in a partially self-limiting nature that makes it possible to dry wet areas without overdrying already dry areas, which is not possible in conventional kilns. Not only is board uniformity increased, but the energy otherwise used for overdrying is saved. Thus the cost of dielectric heating would be reasonable if the wet areas were not extensive, especially since it could then result in a substantial increase in drying capacity.

CONCLUSIONS

A method of determining the moisture distribution during the drying of insulation board was developed. By slicing the partially dried board into thin layers parallel to the surface and determining their moisture content individually, it was found that at the commercially usable drying rates the moisture distributions were very nonuniform after the first few minutes of drying. A dry exterior layer was separated from the still wet interior region by a narrow layer with a very rapidly increasing moisture content. Thus a high percentage of the evaporation was found to take place within the board in a narrow zone that starts at the surface and recedes to the center as drying progresses. Most of the drying at these rates falls in the "second falling rate" classification of general drying theory. The nonuniformity is caused by the limited distance that water can migrate in the time available. The dry exterior layer is responsible for a large part of the total resistance to heat and water vapor transfer.

The potential of increased air velocities is quite limited, since the dry surface layer of the board is already the major factor in limiting heat transfer. This is especially true since costs increase rapidly as air velocity is increased. No significant change in drying mechanism occurred over the range of drying rates studied, so no drastic changes in board properties would be expected in changing from one drying rate to the other in this range during the drying cycle.

Relatively small amounts of dielectric heating would be justified economically, and from a quality control standpoint because it can be used to increase production capacity and uniformity by drying limited areas of high moisture content.

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Creep in Bending of Insulating Fiberboard Roof Deck

T. N. BLAU

The creep in bending of insulating fiberboard roof deck has been examined for a 1-yr. period in order to get a quantitative idea of the deflection caused by continuous and cyclic long-term transverse loads. Roof deck on currently recommended span lengths has supported loads equal to that of the usual roofing materials (1–6 lb./sq. ft.) for 1 year while deflecting less than $^1/_{180}$ of the span length. The creep curve for these materials seems best described by a log-log relationship. For longer span lengths, some of the specimens crept beyond the $^1/_{180}$ point, but upon unloading the creep recovery after four months had reduced deflections to less than $^1/_{180}$ of the span length. There is an indication that fiberboard roof deck has the ability to recover (creep recovery) from short-term cyclic loads without marked hysteresis. The prediction of creep in bending for the materials tested appears possible.

Insulating fiberboard roof deck, since its introduction in 1951, has found increasing acceptance as a building material because it provides in one unit an insulation, a finished ceiling, and a roof sheathing.

Usually, fiberboard roof deck comes in three thicknesses. Selection of the thickness, of course, will depend on the thermal requirements of each geographic location, and the spans. For each thickness, the span lengths shown in Table I have been recommended. The recommendations for the span length of roof deck are based on a maximum allowable deflection of $^1/_{180}$ of the span length (*1*). Sagging greater than this can result in roofs and ceilings that are visually objectionable (*2*).

Owing to the nature of fiberboard, creep in bending was known to occur, just as it does in wood (*3*). A literature search indicated that no data are available on the transverse creep of fiberboard. Therefore, to get a quantitative idea of the deflection caused by long-term, relatively short-term, and cyclic transverse loads, an investigation of creep in bending of insulating fiberboard roof deck was started.

For the past year, creep tests conducted at the Johns-Manville Research Center have indicated the ability of recommended spans of fiberboard roof deck to sustain long-term design loads and to recover from short-term heavy loads.

T. N. Blau, Research Engineer, Materials Evaluation Section, Johns-Manville Products Corp., Research Center, Manville, N. J.

MATERIALS

Standard fiberboard roof deck was tested by measuring periodically the centerpoint deflections of uniformly loaded, simple beams. The materials tested were $1^1/_2$, 2, and 3-in. thick (all nominal), and were representative of roof deck available on the market at the time the investigation was started. The composition and weight of the roof-deck samples tested are shown in Table II. The specimens were tested with the decorative surface under tension.

EXPERIMENTAL

Spans and Loads

Spans and loads were selected to simulate the loads imposed on roof deck by various roofing finishes and minimum load requirements, as shown in Tables III and IV. In addition, one group of roof-deck samples was exposed to stresses well beyond those for which the material was designed, in an attempt to determine creep rupture strength. The spans and loads selected for this investigation are shown in Table V.

Table I. Recommended Span Lengths for Fiberboard Roof Deck (4)

Thickness, in.	*Maximum joist spacing, in.*
1 1/2	24
2	32
3	48

Test Environment

Control of temperature and humidity was not attempted because of the extremely large area of "controlled environment" space required to run an adequate evaluation. However, a log of the temperature and humidity indicated that during this investigation the temperature varied between 80 and 90°F. and the relative humidity between 15 and 80%.

Table II. Construction and Weight of Roof Deck

Nominal thickness, in.	*Construction decorative lamination*	*Remaining laminations*	*Weight, lb./sq. ft.*
1 1/2	1/2-in. building board	Two 1/2-in. sheathing boards	2.7
2	1/2-in. building board	Two 1/2-in. sheathing boards and one 1-in. roofing board	3.9
3	1/2-in. building board	Three 1/2-in. sheathing boards and one 1-in. roofing board	5.2

Test Methods

The sheets of roof deck were tested in a horizontal position and were supported at each end by rounded supports having a diameter of 6 in.

Piano wire (0.010-in. diam.) was strung lengthwise along the center of the top surface of the specimen as the permanent reference point. Tension was maintained in the wire by weights tied to the ends. Aluminum tabs were nailed to the specimen underneath the weighted wire at the two points where the wire hung over the edges of the sample. This prevented the wire from "digging" into the material. A rigid steel rule graduated in 0.01 in. was used to read the deflection at the center of the sample; a point permanently marked on the surface of the sample. Small paper bags filled with sand were used to load the sample uniformly.

Table III. Typical Loads Imposed by Roofing Finishes

Material	*Weight, lb./sq. ft.*
Asphalt shingles	2
Asbestos-cement shingles	4
Slate	10
Clay tile	10–20

Deflection readings were taken before and immediately after loading. Subsequent readings were taken at increasing intervals, since the deflection rate diminished with time.

After about one year, some of the samples were unloaded. Deflection measurements were continued in order to obtain a recovery creep rate. In addition, new specimens were assembled in the same manner as the originals and subjected to cyclic loads for comparison purposes.

Table IV. Minimum Load Requirements

Geographic location	*Pertinent building codes*	*Minimum load requirements, lb./sq. ft.*
Varied	National Building Code	20, or where more than 20, loads as determined by the location
Southern (Inland)	Southern Standard Building Code	10 (heights less than 10 ft.)
(Coastal)		25
West Coast	Uniform Building Code	12–20
East Coast and Midwest	Basic Building Code	20 live load, or snow loads as determined

Table V. Spans and Loads Tested During This Investigation

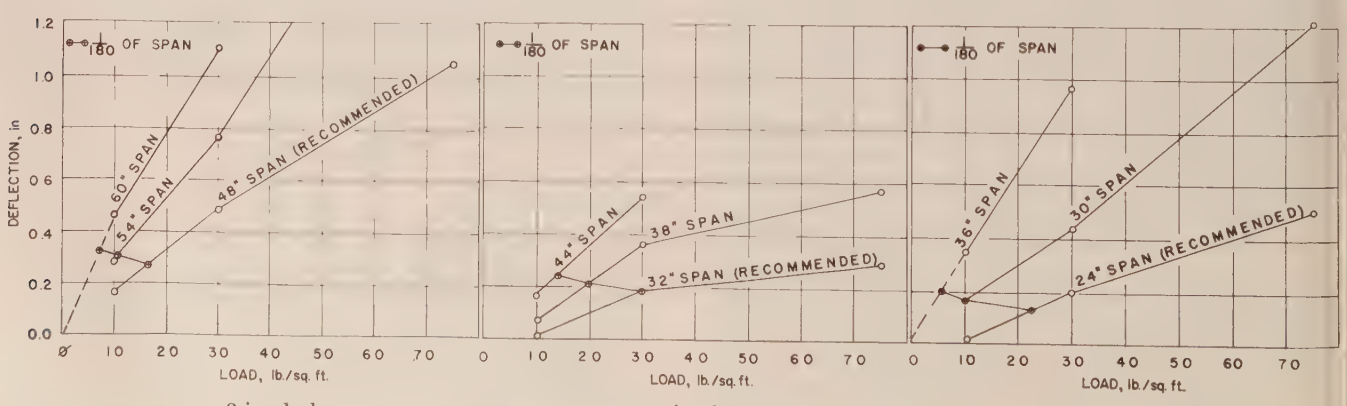
Material thickness, in.	*Spans, in.*	*Loads applied to each span, lb./sq. ft.*
1 1/2	24, 30, 36	10, 30, 75
2	32, 38, 44	10, 30, 75
3	48, 54, 60	10, 30, 75

Specimens tested as simple beams are not as rigid as roof deck applied in the field, which are usually nailed in place over two or more joists. For example, 3-in. thick roof deck uniformly loaded with a 75-lb. per sq. ft. load over a 32-in. span deflected 0.17 in. when stressed as a simple beam, and only 0.11 in. when tested in the field-applied manner. Thus, conclusions based on simple beam data are conservative.

RESULTS

Creep in Bending

Figures 1 to 3 show the maximum deflections reached after one year. These curves do not necessarily represent equilibrium conditions, since a number of similar specimens still under load are continuing to be deflected under creep conditions. However, from these



3-in. deck 2-in. deck 1 1/2-in. deck

Fig. 1–3. Deflections after one year

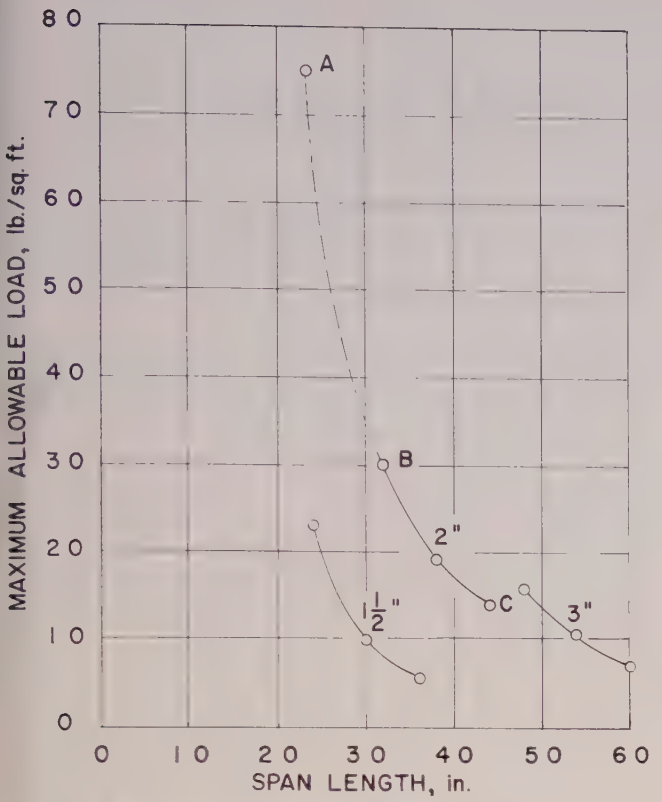


Fig. 4. Maximum allowable load based on 1/180 deflection of span length

three figures, it can be seen that currently recommended spans of fiberboard roof deck have adequately supported loads somewhat greater than the usual roof finishes (1–6 lb./sq. ft.). The term "adequately" in this case is taken to mean that the specimens have not deflected more than $^1/_{180}$ of their span lengths.

The $^1/_{180}$-deflection points for each span length are marked on each curve shown in Figs. 1 to 3. For two of the span lengths, the $^1/_{180}$ points occurred below 10 lb. per sq. ft. (the minimum load investigated), and were marked on the extrapolated portion of the curve. The extrapolation was performed by extending each of the two curves to zero load and zero deflection. One of the curves is that representing the 60-in. span shown in Fig. 1; the other is that representing the 36-in. span shown in Fig 3.

A plot of the span length versus the load at a deflection of $^1/_{180}$ of the span (taken from Figs. 1 to 3) is

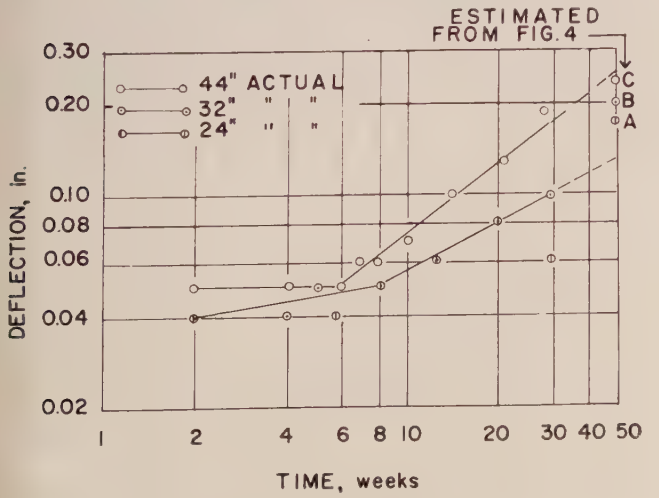


Fig. 5. Actual and estimated deflections of 2-in. deck

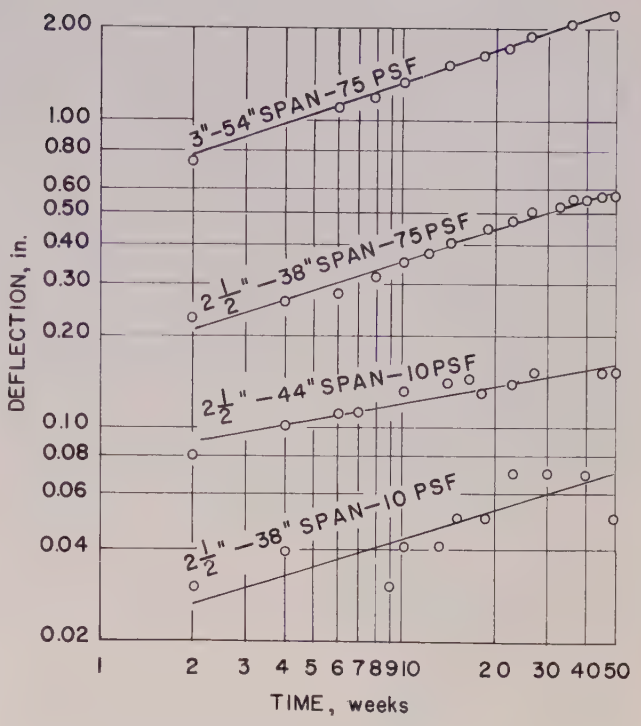


Fig. 6. Typical creep curves

shown in Fig. 4 for each of the thicknesses investigated. In general, Fig. 4 shows that span lengths longer than those currently recommended have a decreased load. carrying capacity (maximum allowable load). For example, increasing the span of 2-in. thick roof deck from 32 to 44 in. causes the maximum allowable load to drop from 30 to 14 lb. per sq. ft. However, on the basis of these creep data, the currently recommended span lengths appear conservative, and some increases may be allowable, especially in the $1^1/_2$ and 2-in. materials.

During the course of this investigation, the results after 5 months were used to estimate the creep in bending of roof deck subjected to loads and spans not yet tested. Figure 5 shows the estimated deflections and the actual deflections. These curves are drawn on log-log paper to provide a linear relationship that can be extrapolated readily. By extending the curves in Fig. 5, it can be seen that the sample having a 44-in. span will have a deflection after one year of 0.02 in. greater than that predicted in Fig. 4 by point *C*. The specimen having a span length of 32 in. will have a deflection after one year of 0.06 in. less than that predicted by point *B* (Fig. 4). The location of the curve for the material with a 24-in. span is not clear. However, it has been found that most of the creep curves located in the small deflection region of the log-log plot had a vague linear relationship; whereas those located in the large deflection portion had an excellent linear relationship. Some typical time–deflection curves plotted on a log-log scale show this clearly (Fig. 6). The apparent nonlinearity in the low deflection region is probably due to the magnification of small differences in this area and limitations of measurement of deflection.

Another type of roof deck (inorganic-bonded wood fiber) has been under test for about seven months, and these specimens are following the same type of time–deflection curves as those for fiberboard roof deck. The spans and loads used for these materials were also esti-

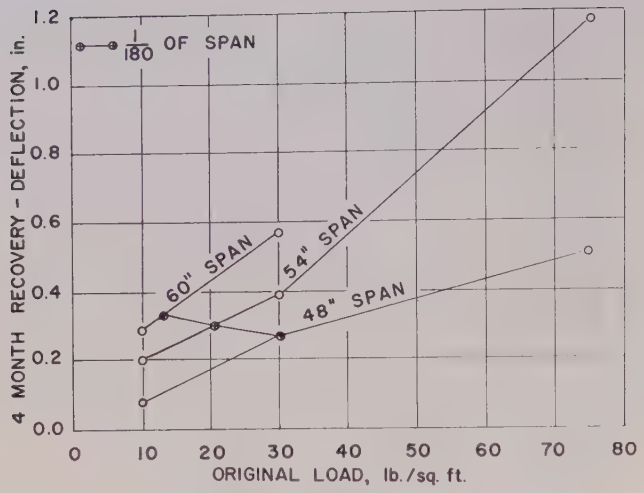


Fig. 7. Creep recovery deflections after 4 months, 3-in. deck

mated by means of the curves shown in Fig. 4. Up to four months these estimates appear reasonable.

Creep Recovery

After one year the samples of 3-in. thick roof deck were unloaded. The creep-recovery rate was rapid at first but slowed down with time. Figure 7 shows recovery curves constructed in a manner similar to that of the loading curves; they represent the minimum deflections reached because of creep recovery after four months. All the specimens originally loaded at 10 lb. per sq. ft. recovered to reflections well below the $^1/_{180}$ point. It is expected that recovery will continue with time until equilibrium is reached. Probably, there is a time–stress point beyond which recovery to the $^1/_{180}$-span deflection will not occur. However, further data on recovery will be required to find this relationship.

The important characteristic shown by these recovery data is the similarity in slope between the initial portions of the loading and recovery curves, although the slopes are of opposite sign, as shown by a typical example in Fig. 8.

Cyclic Loading

Tests with 2-in. roof deck subjected to alternate loads of 10 and 30 lb. per sq. ft. have shown that the overall deflection is actually much less than that estimated on the basis of long-term data under 30 lb. per sq. ft. From Fig. 9 the continuous 30-week deflection of 2-in.

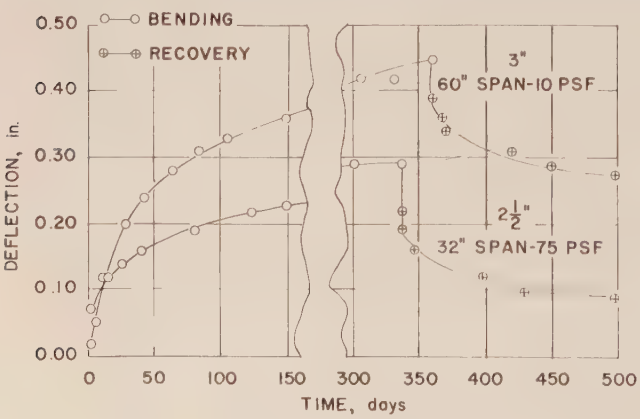


Fig. 8. Similarity between creep in bending and creep in recovery—typical examples

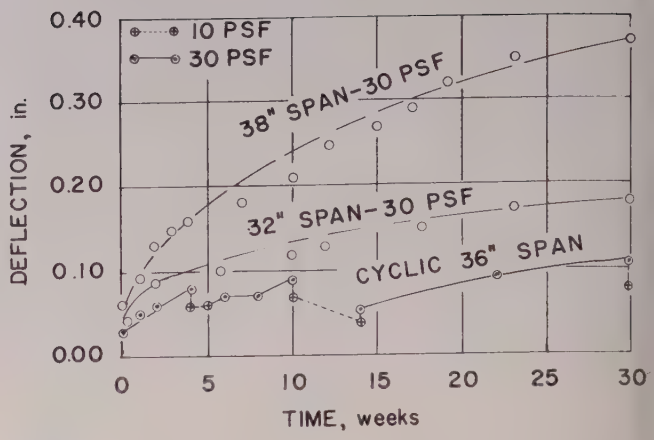


Fig. 9. Cyclic and continuous creep tests, 2-in. deck

roof deck over a 36-in. span can be estimated by extrapolating between 32- and 38-in. span data obtained for 30 lb. per sq. ft. loading during this investigation. The deflection after 30 weeks is seen to be between 0.18 and 0.37 in.

The cyclic 36-in. span roof deck was stressed for 30 weeks with a 30-lb. per sq. ft. load except for a 1- and 4-week period when the load was reduced to 10 lb. per sq. ft. The deflection of this material was only 0.11 in., as shown in Fig. 9. This would indicate that there is a time–stress factor below which recovery is almost 100%; and that on reloading, creep in bending starts from close to zero deflection, as if the material had never been stressed.

This ability to recover without marked hysteresis is an important characteristic of roof deck. Subjected to short-term heavy loads, such as heavy snows or continuous high winds, the roof deck may deflect beyond the $^1/_{180}$ point, but this deflection will apparently be temporary.

CONCLUSIONS

1. Currently recommended spans of fiberboard roof deck have adequately supported loads somewhat greater than that of the usual roofing materials (1–6 lb. per sq. ft.) for a continuous period of one year.
2. For span lengths longer than those currently recommended, the deck may creep beyond $^1/_{180}$ of its span length; but appears capable of creep recovery to a satisfactory deflection.
3. Cyclic loading and recovery tests have indicated that fiberboard roof deck has the ability to recover from short-term cyclic loads without marked hysteresis.
4. Data developed appear to lend itself fairly well to the prediction of creep in bending for the materials tested.

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The author wishes to acknowledge the assistance of Mr. George Dawe in building and setting up the test assemblies.

ASSOCIATION NEWS AND EVENTS

National Conferences

1961

Eleventh Corrugated Containers Conference, Sept. 6–8, 1961, St. Francis Hotel, San Francisco, Calif.

Fourth International Mechanical Pulping Conference, Sept. 19–21, 1961, Edgewater Beach Hotel, Chicago, Ill.

Sixth Deinking Conference, Oct. 4–6, 1961, Hotel Harris, Kalamazoo, Mich.

Sixteenth Plastics-Paper Conference, Oct. 9–11, 1961, French Lick Sheraton Hotel, French Lick, Ind.

Sixteenth Engineering Conference, Oct. 15–19, 1961, Shoreham, Hotel, Washington, D. C.

Fifteenth Alkaline Pulping Conference, Nov. 1–3, 1961, Rice Hotel, Houston, Tex.

1962

Forty-seventh Annual Meeting, Feb. 18–22, 1961, Commodore Hotel, New York, N. Y.

Thirteenth Coating Conference, May 14–16, 1962, Netherland-Hilton Hotel, Cincinnati, Ohio.

Thirteenth Testing Conference, Sept. 18–20, 1962, Benjamin Franklin Hotel, Philadelphia, Pa.

Seventeenth Plastics-Paper Conference, Oct. 8–11, 1962, Statler-Hilton Hotel, Boston, Mass.

Seventeenth Engineering Conference, Oct. 14–19, 1962, Queen Elizabeth Hotel, Montreal, Que.

Twelfth Corrugated Containers Conference, Oct. 23–26, 1962, Statler-Hilton Hotel, Boston, Mass.

Sixteenth Alkaline Pulping Conference, Oct. 31, Nov. 1–2, 1962, DeSoto Hotel, Savannah, Ga.

1963

Fourteenth Coating Conference, May 19–22, 1963, Concord Hotel, Kiamesha Lake, N. Y.

Thirteenth Corrugated Containers Conference, Oct. 22–25, 1963, Statler-Hilton Hotel, Detroit, Mich.

Eighteenth Engineering Conference, Oct. 28–31, 1963, Netherland-Hilton Hotel, Cincinnati, Ohio.

Other Meetings

On Sept. 28, 29, and 30, 1961, the Chemical Division of the American Society for Quality Control is holding its Fifth Annual Chemical Conference at the Daniel Boone Hotel in Charleston, W. Va.

Technical Section of the British Paper and Board Makers' Association, Sept. 25–29, 1961, Symposium: The Formation and Structure of Paper, Oxford, England.

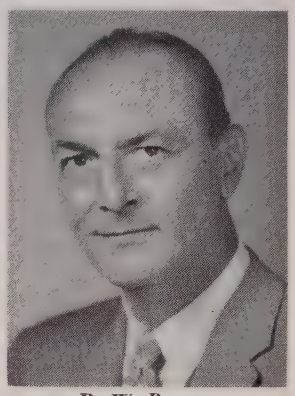
Papirindustriens Tekniske Forening, Dec. 5–6, 1961, Technical Convention, Oslo, Norway.

Year Book Listings

All members are urged to inspect their respective listing in the 1960–1961 TAPPI Year Book and notify the Association before September 15 if changes are to be made in the next edition.

Fourdrinier Committee

Ralph W. Peters, 249 Hollywood Ave., Rochester, N. Y., assistant superintendent of the Paper Mills Division of Eastman Kodak Co., Rochester, N. Y., was appointed chairman of the Fourdrinier Committee of the Technical Association of the Pulp and Paper Industry in May, 1961. Previous to this appointment, Mr. Peters was secretary and vice-chairman of this committee. He has been a member of the association since 1947.



R. W. Peters, Eastman Kodak Co., Chairman, Fourdrinier Committee

Mr. Peters is a graduate of M.I.T. with a B.S. degree received in 1930, and an M.S. degree received in 1931.

He has presented technical papers at the Lake States Meeting in 1954, Engineering Committee Annual Meeting in Boston, in 1957 and at the Annual Meeting of the Association in 1958. He has a broad background in the paper industry, and is a member of the Paper Industry Management Association.

Graphic Arts Committee

H. A. Samuelson, Consolidated Water Power & Paper Co., Wisconsin Rapids, Wis. was appointed chairman of the Subcommittee for Surface Strength of Paper of the Graphic Arts Committee of the Coating and Graphic Arts Division of TAPPI in Chicago on April 19, 1961. Other appointments to the subcommittee were Alan C. Hamilton, Oxford Paper Co., Rumford, Me., Marlin Lovensheimer, The Mead Corp., Chillicothe, Ohio, and Robert L. Hagerman, Dow Chemical Co., Midland, Mich.

It was also decided at this meeting to conduct a round-robin series of tests on a suggested method for determining surface strength of paper to be published in the near future. This method is the result of work done at the National Printing Ink Research Institute at Lehigh University, Bethlehem, Pa., and directed by the Surface Strength Subcommittee under the chairmanship of Alex Glassman, R. R. Donnelley & Sons Co., Chicago, Ill. The work was supported by grants from the TAPPI Project Appropriations fund.

The ground work for the round-robin study will be ready soon. TAPPI members interested in participating in these tests may contact the subcommittee chairman.

W. C. Walker, West Virginia Pulp and Paper Co., Williamsburg, Pa., a member of the Graphic Arts Committee, presided as moderator of a symposium and panel discussion on "Paper and Printing" at the 6th Annual Symposium, held by the Eastern District of the Empire State Section of the TAPPI in the Queensbury Hotel, Glens Falls, N. Y., on April 20, 1961. The speakers presented papers covering the particular field in which they are an expert. F. W. Goetz, Publication Corp., New York, N. Y., talked on "Gravure Printing." Earl Brown McCall Corp., Dayton, Ohio, reviewed "Letterpress Printing," while William Palinski, Western Printing and Lithographing Co., Poughkeepsie, N. Y., covered "Offset Printing."

All three speakers are members of TAPPI. Mr. Walker is

Technical Officer of the Graphic Arts Committee of the Coating and Graphic Arts Division of TAPPI.

Standards, Data Sheets, and R.C. Methods

Two mailings of loose-leaf sheets of TAPPI Standards, Data Sheets and Routine Control Methods have recently been sent to the members of the Association.

The TAPPI Routine Control Methods mailing included 19 new methods and four revised methods. A revised and expanded alphabetical and numerical index was also included. The index is cross-referenced in as many ways as possible to ease the effort of locating a method.

There were eight new TAPPI Data Sheets issued, together with a revised index and a sheet indicating the titles of the new sheets and the titles and code numbers of data sheets that have been withdrawn. The withdrawn sheets have been studied by appropriate committees and for various reasons such as obsolescence, inaccuracy, etc., have been discarded. In some cases these sheets may be reissued with new code numbers.

The new sheets include:

202 Approximate Requirements for Electric Power in Pulp Bleaching (Revision)
203 Roll Storage Capacities and Floor Loading
204 Flow Process Symbols
205 Digester Design
206 Winder Drive Power Requirements—Mean of Experienced Values
207 Winder Drive Power Requirements
208 Winder Generator Power Requirements
209 Recommended Voltage Levels for A.C. Polyphase Motors

There were 38 corrected revised and new TAPPI Standards and methods issued together with a ballot relating to seven methods being considered for advancement to official standard status.

The methods include:

T 2 m Methoxyl Groups in Wood
T 3 m Moisture in Wood Chips and Sawdust by Toluene Method
T 200 m Laboratory Processing of Pulp (Beater Method)
T 208 m Moisture in Pulp by Toluene Distillation
T 220 m Physical Testing of Pulp Handsheets
T 225 sm Laboratory Processing of Pulp (Kollergang Method)
T 231 sm Zero-Span Breaking Length of Pulp
T 234 sm Coarseness of Pulp Fibers
T 235 m Solubility of Pulp in Sodium Hydroxide at 20°C.
T 236 m Kappa Number of Pulp
T 401 m Fiber Analysis of Paper and Paperboard
T 405 m Paraffin in Waxed Paper
T 406 m Reducible Sulfur in Paper and Paperboard
T 419 m Starch in Paper
T 425 m Opacity of Paper
T 439 m Titanium Pigments in Paper
T 441 m Water Absorptiveness of Nonbibulous Paper and Paperboard (Cobb Test)
T 451 m Rigidity, Stiffness, and Softness of Paper
T 454 m Turpentine Test for Grease Resistance of Paper
T 468 m Water-Soluble Sulfates and Chlorides in Paper and Paperboard
T 478 sm Ink-Erasing Quality of Paper
T 481 sm Fiber Orientation and Squareness of Paper (Zero-Span Tensile Strength)
T 489 m Stiffness of Paperboard
T 491 sm Water Immersion Test of Paperboard
T 492 sm Water Absorption of Paperboard
T 610 m Preparation and Standardization of Volumetric Solutions
T 612 m Analysis of Soda Ash (Anhydrous Sodium Carbonate)
T 624 m Analysis of Soda and Sulfate White and Green Liquors
T 632 m Analysis of Sodium Silicate
T 634 m Melting Point of Petrolatum and Microcrystalline Wax
T 639 sm Needle Penetration of Petroleum Waxes
T 644 m Tensile Strength of Paraffin Wax
T 652 sm Blocking Range of Paraffin Wax
T 655 sm Modulus of Rupture of Petroleum Waxes
T 1000 m Thermal Conductivity of Structural Insulating Board
T 1001 m Forming Insulating Boards for Physical Tests
T 1002 sm Drainage Time of Pulp for Insulating Board
T 1003 m Flexural Resistance and Deflection of Insulating Board.

Considerable changes have been made in the typograph used in printing the Standards to improve readability and clarity.

Metropolitan District

The first meeting of the Metropolitan District of the Empire State Section will be held at Stauffers Restaurant, 100 E. 42nd St., New York, N. Y., on Tuesday, Sept. 12, 1961. The speaker will be Howard E. Whitaker, chairman of the board, The Mead Corp., Chillicothe, Ohio, and president of the American Paper and Pulp Association.

Berkshire District

The Berkshire District of the New England Section will hold its meetings at the Country Club of Pittsfield, Mass., on Nov. 21, 1961, Jan. 16, 1962, and May 15, 1962. On March 30, 1962, it will meet at the Wendell Sherwood Hotel in Pittsfield.

Ohio Section

The Ohio Section has scheduled the following meetings to be held this fall:

Sept. 12, 1961, at the Manchester Hotel, Middletown, Ohio, "Application of High Polymers to Paper and Board," by Paul McLaughlin of Rohm & Haas Co., Philadelphia, Pa.
Oct. 12, 1961, at Chillicothe, Ohio. Visit to the laboratories of The Mead Corp. Seminar.
Nov. 14, 1961, at the Manchester Hotel, Middletown Joint Meeting with the Miami Valley Division of PIMA. Discussion of modern paper machines.
Dec. 14, 1961, at the Manchester Hotel. "Effects of Refining on Fiber Structures," by Renata Marton, ESPRA, Syracuse University, Syracuse, N. Y.

On March 13, 1962, a joint meeting with the Indiana District and the staff of the Miami University Pulp and Paper School will be held at Oxford, Ohio. Herman Mark, professor of the Polytechnic Institute of Brooklyn, will be the speaker.

Eleventh Corrugated Containers Conference

The 11th Corrugated Containers Conference of the Technical Association of the Pulp and Paper Industry is scheduled for Sept. 6–8, 1961, at the St. Francis Hotel in San Francisco, Calif.

The conference will feature "Adaption of Flexographic Printing to Corrugated" and the "Use of Corrugated Containers in the Agricultural Field on the West Coast." New engineering developments will also be discussed.

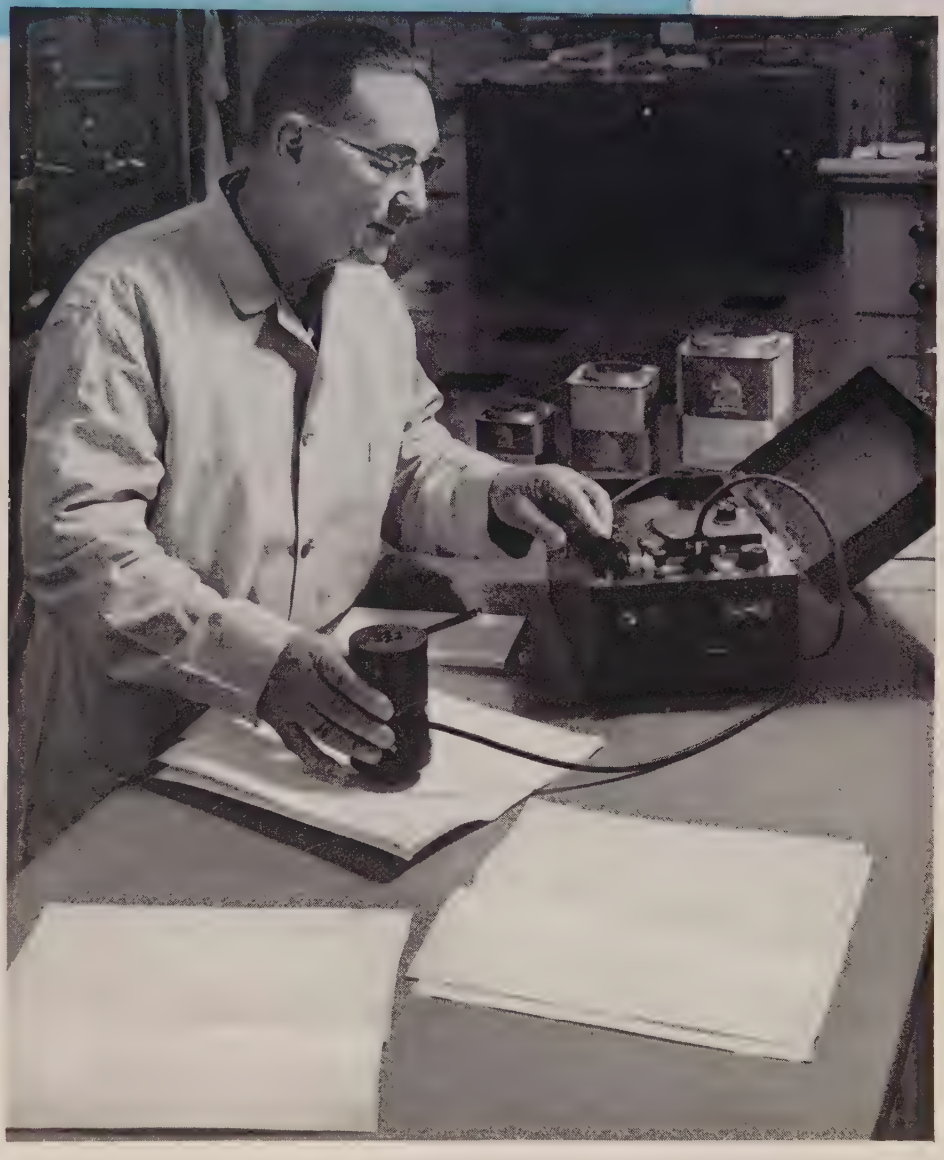
H. T. Scordas, Union Bag-Camp Paper Corp., New York, N. Y., publicity chairman, has announced details of the two plant tours planned for the conference registrants:

Longview Fibre Co., Oakland, Calif.
Royal Container Division, Georgia Pacific Paper Co., Millbrae, Calif.

The Royal Container plant started operations at Millbrae in 1940. It produces in excess of 600,000,000 sq. ft. per year on a three-shift, 5-day-plus per week basis. The plant has 180,000 sq. ft. and its principal equipment includes the following:

1—87 in. S&S corrugator, B and C combination with W-S design corrugating rolls for production of double face
1—80 in. S&S corrugator A and B for production of single face
2—38 × 78 S&S printer slotters (two color)

Step Up Paper Brightness with HORSE HEAD® TITANIUM DIOXIDE



Paper brightness measurements are made with the photo volt meter in determining whitening characteristics of titanium dioxides.

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Why wait for paper buyers to set the brightness standard for your products?

Utilizing the extremely high refractive index and reflectivity of HORSE HEAD titanium dioxide, you can impart maximum brightness to your papers now . . . before your customers demand it.

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Founded 1848

Also distributed by BULKLEY DUNTON PULP CO. INC. • New York, N. Y. • Kalamazoo, Mich. • San Francisco, Calif.

Royal Container Div., Georgia Pacific Paper Co., Millbrae, Calif.

1—54 × 127 S&S printer slotter (two color)
1—38 × 80 H&C flexographic printer (two color)
1—32 × 72 Bostitch Equalok folder-gluer
1—Royal Container—Royal Packer
1—50 × 80 Sheridan die cutter

Unusual equipment and operations to be seen would include:

1. The Royal Packer and its unit called the Royal-Pak
2. Flexographic printing
3. W-S design corrugating rolls
4. A Bostitch Sheridan typer

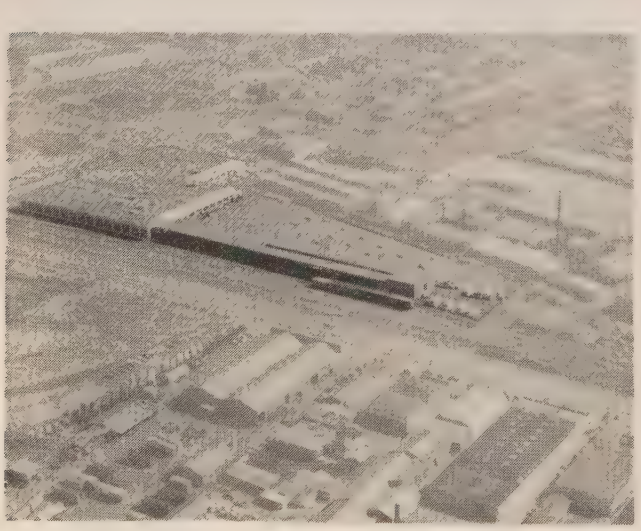
The Oakland plant of Longview Fibre Co. started operations in 1950. It occupies a 7-acre plant site with approximately 215,000 sq. ft. under roof. This space is split about evenly between operating and storage space.

Normal production is about 30,000,000 sq. ft. per month on a two 8-hour shift, five-day-per-week basis.

Corrugating equipment consists of two Langstons, one 85 and one 78 in. This fall the 78-in. will be equipped with the latest model Langston rotary cutoff as well as a new model batching side delivery on one of the knife stations. Both corrugators are equipped with belt driers.

Six printer-slotters and miscellaneous slitting, die cutting, and rotary die cutting equipment allow for handling a full range of product. Five of the printer slotters are fitted with automatic stackers and fountain washers.

The joining equipment consists of conventional taping and stitching equipment as well as one Bostitch Equalok and one Universal Comet. The Equalok is fitted with Martin rotary die cutting shafts between the slotting section and the belts.



Longview Fibre Co., Oakland, Calif.

It has a counter-ejector. The Comet will also shortly be fitted with the newest model counter ejector.

Shipping and receiving facilities consist of a rail siding with a capacity for 16 cars as well as a truck dock and truck loading areas.

The area sales office is located at this plant.

H. W. Wilson, Royal Container Div., Georgia Pacific Paper Co., San Francisco, Calif., and O. P. Wanamaker, Fibreboard Paper Products Corp., Antioch, Calif., are general co-chairmen of the conference. Mr. Wanamaker is also technical program chairman, assisted by R. W. Catzen, Baltimore Box Co., Baltimore, Md.; G. M. Caploe, Longview Fibre Co., Oakland, Calif.; A. Richardson, Crown Zellerbach Corp., St. Louis, Mo.; J. E. Knecht, Bathurst Containers, Ltd., Montreal, Que.; and L. F. Ashwood, Downing Box Co., Milwaukee, Wis.

Committees of the Corrugated Containers Division will meet on Tuesday, Sept. 5, 1961. The meeting schedule is as follows:

9:00 a.m.	Steering and Advisory Council (Mayfair Suite)
9:00 a.m.	Engineering Committee (Olympic Suite South)
2:00 p.m.	Engineering Committee (Olympic Suite South)
2:00 p.m.	Industrial Engineering Committee (Olympic Suite North)
2:00 p.m.	Process and Quality Control Committee (Oasis Room)
2:00 p.m.	Production Committee (Davenport Suite)
2:00 p.m.	Raw Materials Committee (Cosmopolitan Room)

Registration will begin at 3:00 p.m., Tuesday, September 5, 1961.

Those desiring hotel reservations should write to:

TAPPI 11th Corrugated Containers Conference
St. Francis Hotel
San Francisco, Calif.

and state both dates and times of arrival and departure.

Fourth International Mechanical Pulping Conference

The 4th International Mechanical Pulping Conference of the Technical Association of the Pulp and Paper Industry is scheduled for Sept. 19–21, 1961, at the Edgewater Beach Hotel, Chicago, Ill.

This conference is sponsored by the Mechanical Pulping Committees of TAPPI and Technical Section, CPPA (Canadian Pulp and Paper Association). TAPPI Committee chairman is T. F. LaHaise, Ryegate Paper Co., East Ryegate, Vt., and Technical Section, CPPA Committee chairman is H. P. Richards, Ontario Paper Co., Thorold, Ont.

The general conference chairman is W. H. de Montmorency, The Pulp and Paper Research Institute of Canada, Montreal, Que., S. R. Parsons, Consolidated Water Power and Paper Co., Wisconsin Rapids, Wis., is technical program chairman. Publicity chairman is W. H. Copeland, Norton Co. of Canada, Hamilton, Ont., and A. A. Yankowski, Irving Pulp and Paper Co., Lancaster, N. B., is local arrangements chairman.

High lights of the conference will relate to papers on grinding fundamentals, chip groundwood, bleaching, new techniques for increased capacity of existing grinders, and improved quality of pulp. A number of international experts in mechanical pulping are expected to attend, some of whom will present papers.

Robert K. Burns, Associate Dean of Graduate School of Business and Executive Director of Industrial Relations Center, University of Chicago, Chicago, Ill., will be the banquet speaker on Wednesday Sept. 20, 1961.

Those desiring hotel reservations should write to:

TAPPI 4th International Mechanical Pulping Conference
Edgewater Beach Hotel
5300 Block—Sheridan Road
Chicago 40, Ill.

stating both dates and times of arrival and departure.

Sixth Deinking Conference

The 6th Deinking Conference of the Technical Association of the Pulp and Paper Industry scheduled Oct. 4–6, 1961, at the Hotel Harris in Kalamazoo, Mich., has as its theme "Bleaching of Deinked Stock." G. C. Sisler, Bergstrom Paper Co., Neenah, Wis., has announced the complete technical program. The following papers will be presented:

"Economic Considerations in the Bleaching of Deinked Stock," by Paul Schmitt, P. H. Glatfelter Co., Spring Grove, Pa.
"Fundamental Aspects of Color Reversion," A. H. Nadelman, Kalamazoo, Mich.
"Bleaching of Deinked Stock," by G. H. Baldauf, Allied Paper Corp., Kalamazoo, Mich.
"A Brief Description of Bergstrom Paper Co. Three-Stage Bleach Plant," by J. D. Allen, Bergstrom Paper Co., Neenah, Wis.
"Single versus Multiple Stage Bleaching of Deinked Stock," by A. D. Harbin, Diamond Alkali Co., Painesville, Ohio
"Use of Peroxides in Bleaching Deinked Stock," by R. R. Kindron, Food Machinery & Chemical Corp., Buffalo, N. Y.
"Use of Zinc Hydrosulfite for Removing Dyes from Paper," by R. W. Barton, Virginia Smelting Co., West Norfolk, Va.
"Design Features of Kimberly-Clark Moraine Mill's New Deinking System," by W. C. Martin, Kimberly-Clark Corp., Moraine Div., West Carrollton, Ohio

S. J. Stetz, Allied Paper Co., Kalamazoo, Mich., general conference chairman, has announced other details of the conference. J. D. Dailey, Sr., vice-president of Allied Paper Co., Kalamazoo, Mich., will be the guest speaker at the banquet on Thursday, October 5. The Kalamazoo Valley Section of TAPPI, J. D. Chadderdon, KVP-Sutherland Paper Co., Kalamazoo, Mich., chairman, will hold its October meeting in conjunction with the Deinking Conference banquet.

Plans have been made for plant tours to Allied's King and Bryant mills, and to Pioneer Paper Stock Co.

The Deinking Committee, A. J. Felton, Black-Clawson Co., Shartle Division, Middletown, Ohio, chairman, will meet Wednesday, 7:00 p.m., Oct. 4, 1961, at the Hotel Harris.

Those planning to attend the conference should write to the following address for hotel reservations:

TAPPI 6th Deinking Conference
Hotel Harris
Kalamazoo, Mich.

and state both times and dates of arrival and departure.

Sixteenth Plastics-Paper Conference

The 16th Plastics-Paper Conference of the Technical Association of the Pulp and Paper Industry is scheduled for Oct. 9–11, 1961, at the French Lick-Sheraton Hotel in French Lick, Ind.

T. A. Howells, The Institute of Paper Chemistry, Appleton, Wis., technical program chairman, has announced further details of the program.

There will be a panel discussion on the subject of "The Growing Importance of Man-Made Fibers to the Paper Industry." H. E. Shearer, American Viscose Corp., Marcus Hook, Pa., will moderate the session. The panelists are:

D. G. Bannerman, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.
C. L. Hazelton, Blandy Paper Div., Hollingsworth and Vose Co., Schylersville, N. Y.
W. F. Reynolds, American Cyanamid Co., Stamford, Conn.
W. K. Saunders, Kimberly-Stevens Co., New York, N. Y.
H. A. Spencer, Knowlton Bros., Watertown, N. Y.
W. R. Wilson, American Viscose Corp., New York, N. Y.

Other information on the program was published in July *Tappi*.

Attention is called to the fact that French Lick is approximately 100 miles from the Indianapolis airport and approximately 65 miles from the Louisville, Ky. airport. Detailed information on transportation to French Lick from either airport is provided in July *Tappi*.

Those wishing hotel reservations should write to:

16th Plastics-Paper Conference
French Lick-Sheraton Hotel
French Lick, Ind.

and state both dates and times of arrival and departure.

Sixteenth Engineering Conference

The 16th Engineering Conference of the Technical Association of the Pulp and Paper Industry is scheduled for Oct. 16–19, 1961, at the Shoreham Hotel in Washington, D. C.

There are 59 technical papers (18 sessions, scheduled for presentation on the conference theme "Cost Reduction Through Engineering." B. R. Cancell, executive vice-president of St. Regis Paper Co., New York, N. Y., will deliver the keynote address Monday morning, Oct. 16, 1961.

James E. Webb, administrator, Aeronautics and Space Administration, will be the guest speaker at the banquet on Wednesday, Oct. 18, 1961.

A modest but interesting ladies' program is being planned by Mrs. W. S. Allmond, Hopewell, Va., and will include a trip to Mt. Vernon and a visit to the White House. A dance will be held after the Wednesday banquet.

Attention is called to the committee meetings which will occur during the conference according to the following schedule:

MONDAY: OCT. 16, 1961

9:00 a.m.	Electrical Engineering Steering Committee (West Room)
2:00 p.m.	Electrical Engineering Subcommittees (West Room)

TUESDAY: Oct. 17, 1961

9:00 a.m.	Electrical Engineering Subcommittees (Park Room)
12:30 p.m.	Sanitary Engineering Committee (Lunch) (North Room)
12:30 p.m.	Chemical Engineering Committee (Lunch) (South Room)
12:30 p.m.	Industrial Engineering Committee (Lunch) (South Room)
12:30 p.m.	Corrosion Committee (Lunch) (Club Room)
2:00 p.m.	Operations Research Committee (East Room)
2:00 p.m.	Process Instrumentation Committee (Park Room)

WEDNESDAY: Oct. 18, 1961

9:00 a.m.	Electrical Engineering Subcommittees (Park Room)
12:30 p.m.	Fluid Mechanics Committee (Lunch) (Club Room)
12:30 p.m.	Construction Engineering Committee (Lunch) (South Room)
12:30 p.m.	Electrical Engineering Committee (Lunch) (Park Room)

THURSDAY: Oct. 19, 1961

12:30 p.m.	Steam and Power Committee (Lunch) (Park) Room)

Those desiring hotel reservations should write to:

TAPPI 16th Engineering Conference
Shoreham Hotel
Washington, D. C.

stating both times and dates of arrival and departure.

Bound Volume—Technical Section
1960 TAPPI

Each year the pages of the Technical Section of *Tappi* are accumulated and bound in a cloth cover as a single volume. These volumes are usually ordered by members in advance. There are some copies of the 1960 volume available at $5.00 per copy and may be obtained from the Technical Association of the Pulp and Paper Industry, 360 Lexington Ave., New York 17, N. Y.

Fifteenth Alkaline Pulping Conference

The 15th Alkaline Pulping Conference of the Technical Association of the Pulp and Paper Industry is scheduled for Nov. 1–3, 1961, at the Rice Hotel in Houston, Tex.

T. T. Collins, Packaging Corp. of America, Filer City, Mich., is technical program chairman for the alkaline pulping sessions.

Among the papers to be presented on alkaline pulping are the following:

1. "Unbleached Kraft Color," by J. W. Daniel, Union Bag-Camp Paper Co., Savannah, Ga.
2. "Determination of Sulfide and Methyl Mercaptan in Sulfate Black Liquor," by R. F. Cashen and H. D. Bauman, P. H. Glatfelter Co., Spring Grove, Pa.
3. "Survey of Nonconventional Alkaline Pulping Processes," by E. F. Thode, The Institute of Paper Chemistry, Appleton, Wis.; H. C. Crandall, Mosinee Paper Mills Co., Mosinee, Wis.; and N. S. Thompson, The Institute of Paper Chemistry, Appleton, Wis.
4. "Kraft Black Stock Screening," by R. R. Fuller, Gulf States Paper Co., Tuscaloosa, Ala.
5. "Outdoor Storage of Hardwood Chips," R. A. Flick, Brunswick Pulp and Paper Co., Brunswick, Ga.

In addition, there will be panel discussions on each of the above two subjects, moderated by the respective authors.

E. D. Cann, Chas. T. Main, Inc., Boston, Mass., is the technical program chairman for the sulfite pulping session. The following papers are scheduled for this portion of the conference:

1. "Studies in Full Chemical Pulping II. Carbohydrate Changes and Related Physical Effects." by N. S. Thompson, J. R. Peckham, and E. F. Thode, The Institute of Paper Chemistry, Appleton, Wis.
2. "The Role of Carbonyl Groups in the Sulfonation of Spruce Wood Lignin," by P. Luner and H. P. Gore, State University of New York College of Forestry, Syracuse, N. Y.
3. "Solubility and Neutralization Equilibria in the Magnesium-Base Sulfite Acid System," by R. B. Kesler and S. T. Han, The Institute of Paper Chemistry, Appleton, Wis.

J. O. Parrott, Champion Paper and Fibre Co., Pasadena, Tex., local arrangements chairman has announced that three mill tours will be available to the conference registrants:

1. Champion Paper and Fibre Co., Pasadena, Tex.
2. East Texas Pulp and Paper Co., Evadale, Tex.
3. Southland Paper Mills, Inc., Lufkin, Tex.

Those planning to take one of the out-of-town tours must indicate their intentions by Wednesday noon, Nov. 1, 1961.

The Diamond Alkali Co. plant at Deer Park, Tex. will also be open for personally scheduled tours.

Karl Bendetsen, president of Champion Paper and Fibre Co., will present an address "The Tides of Liberty" at the Conference luncheon on Wednesday, November 1.

Marvin Hurley, executive secretary of the Houston Chamber of Commerce will adddress the group at the Thursday luncheon. His topic is "Community Leadership."

Mr. Parrott also has announced there will be a modest but interesting ladies' program.

Those planning to attend the conference should write to

TAPPI 15th Alkaline Pulping Conference
Rice Hotel
Houston, Tex.

for hotel reservations and state both times and dates of arrival and departure.

A.T.C.P. Annual Meeting

The annual meeting of the Asociacion Mexicana de Tecnicos de las Industrias de la Celulosa y del Papel, A.C. was held at the Hotel Presidente, Mexico City, D. F., on May 25, 1961.

TAPPI was represented by Harry S. Goodshall, plant manager of Compania Industrial de San Cristobal, S.A., who presented in Spanish the good wishes of President Annis and the Association.

The principal speaker was Lic. Placido Garcia Raynoso, Under Secretary of Industry and Commerce, who stressed the growing opportunities of the pulp and paper industry in Mexico. He indicated that production of pulp and paper must double by 1970 to keep up with the growing population and to allow for moderate per capita increase.

About 95 members attended the technical sessions, three of which were conducted simultaneously. A luncheon was tendered by the association to the senior executives of the pulp and paper mills of Mexico.

The association organized last year following a visit by R. G. Macdonald, Treasurer and Editorial Director of TAPPI, now has 155 members, representing most of the pulp and paper companies of Mexico. It has held several technical conferences and publishes a technical magazine ATCP. It is also translating into Spanish TAPPI Standard testing methods and other publications.

The following papers were presented at the annual meeting:

Standards and Specifications Section

Rafael Rogas, Laboratories Nacionales de Fomento Industrial, *Moderator*.
"The Laboratory in the Paper Industry," by Salvador Carrasco and Rafael Rogas, L.N.F.I.
"The Use of Paper in Food Wrapping," by Rafael Illeces, L.N.F.I.
"Determination of Consistency," by Erhard Lenz, Fabricas de Papel Loreto y Pena Pobre, S.A.
"Comparative Study of Henter and Photovolt Reflectometers," by Armando Acosta E and Eduardo Lozano, L.N.F.I.
"Investigation and Evaluation of Optical Bleaching Agents," by Armando Acosta E. and Eduardo Lozano.

Pulp Section

I. de la Garza, Compania de las Fabricas de Papel San Rafae y Anexas, S.A., *Moderator*.
"More Productivity of Paper Machinery through the Selection of Pulp," by Robert M. Mayer, Rayonier, Inc.
"Mercaptans and Sulfides in Black Liquor and White Liquors," by M. Guevera, Fabricas de Papel Loreto y Pena Pobre, S.A.
"Chemical Study of Yuca," by Robert Salvador Cassasco, L.N.F.I.
"Diphenyl Mercuric Ammonium Propionate, A New Slime-Control Agent," by Jorge Rodriquez E., Dr. Jose Polak S. A., Metalsalts Corp.
"Comparative Study of the Direct Evaporation of Black Liquor," by M. A. Ramirez, Peralta, Eloff Hansson, S.A.
"Slime in White Water," by S. Mendiola, Fabricas Papel Loreto y Pena Pobre, S.A.
"Preparation and Use of Chlorine Dioxide," by Jaime de la Macorra, Kimberly-Clark de Mexico, S.A.
"Control of Causticizing Plants," by L. Madrigal, Fabricas de Papel Loreta Pena Pobre, S.A.
"Pulp Washing Systems," by R. Rueda L., Processes Industriales, S.A.
"The Production of Pulp from Raw Materials Other than Wood by Use of the Lime Process," by Ava Maria Leal, L.N.F.I.
"Use of Sugar Cane Bagasse as Raw Material in the Manufacture of Paper," by Sergio Martinez, Parsons & Whittemore de Mexico, S.A.

Engineering Section

H. Dorsh, Fabricas de Papel Loreto y Pena Pobre, S.A., *Moderator*.
"Rebuilding a Paper Mill," by Karl Augustin, Lamanas Acanalades Infinitas.
"Effluent Disposal by Sun Evaporation," by Oskar Hentschell C., Celanese Mexicana, S.A.
"Recovery of White Water," by George Soyka, G. E. Soyka and Associates.
"Moisture Control Across the Deckle of a Paper Machine," by J. A. Villalobos, J. O. Ross Engineering Co.
"Design and Development of Centrifugal Cleaners," by representative of Nichols Engineering Co.
"Combustion of Black Liquor," by Edward N. Smith, Combustion Engineering, Inc.
"Fresh Water Showers for Paper Machines," by A. E. Gray, A. E. Broughton & Co., Inc.

"Preliminary Study of a New Wire for Fourdrinier Machines," by Edwin Univin, Capital Wire Cloth & Mfg. Co.

Dissolving Pulp Section

ASKAR HENTSCHEL, Celanese Mexicana, S.A., *Moderator*.
"Alpha Cellulose from Tropical Woods," by Yammick Vellegas, Institute Mexicana de Investigaciones Tecnologicas.
"Cellulose Strength," by Jesus Cardenas, Celanese Mexicana, S.A.
"Evaluation of Pulps for Acetylation," by Ramiro Villarreal Q., Celanese Mexicana, S.A.
"Mechanism of Swelling and Dissolution of Filliform Vegetable Cells by New Solvents."
Film by G. Jayme, Technischen Hochschule, Darmstadt.

Converting Section

M. A. RAMIREZ PERALTA, Eloff Hansson, S.A., *Moderator*
"Winding of Paper and Paperboard," by Eugene Ward, Cameron Machine Co.
"Use of Kaolin in the Paper Industry," by Mark Fritz, J. M. Huber Co.
"Mexican Kaolin for Coated Paper," by Carlos Zonana F., Papel Satinado, S.A.
"Converting Equipment," by representative of Jagenberg Werke A.G.

Paper Section

JAIME DE LA MACORRA, Kimberly-Clark de Mexico, S.A. *Moderator*.
"Control of Caliper and Weight," by W. V. Smiley, W. Bishop, Electric Eye Div., S.A.
"Studies of Felts and Paper Machines," by Emrique Garcia, Fieltros Albany, S.A.
"Application of Urea Formaldehyde Resin to Obtain Wet Strength in Paper," by Eduardo Vidal, Adhesives Resistol, S.A.
"Use of Sizing Agents in Paper," by Ramon Torres U., Nopco Industrial, S.A.
"Influence of Head Box Construction on the Uniformity of Paper," by K. Augustin, Lamminas Acanaladas Infinitas.
"Use of Diacol in the Paper Industry," by representative of Cesalpina, Italy.

Graphic Arts and General Section

ENRIQUE PAROJA, Fabricas de Papel San Rafael y Anexas, S.A., *Moderator*
"Difficulties in Printing Due to Paper," by Ramon Corral, Litografía Senefelder, S.A.
"The Use of Filming Amines in Pulp and Paper Plants," by J.A. Perez, Proveedores Tecnicos, S.A.
"The Use of Silicones in Foam Control in Pulp and Paper Production," by Juan Vinageras, Dow Corning, Inc.
"The Importance of an Industrial Safety Program," by Angel Mendoza Escobedo, Asociation Mesicana y Seguridad, A.C.
"Investigation Facilities" by representative of Instituto Mexicano de Investigaciones Tecnologicas.

JCUMWE 1961 Annual Report

The Joint Committee on Uniformity of Methods of Water Examination (JCUMWE) completed its fifth year of operation as of March 1, 1961. The committee is made up of representatives of 12 technical organizations engaged in the development and publication of methods of water examination. The objectives of JCUMWE are to review methods of examination published by member organizations to obtain uniformity in sampling, testing, reporting test data, and terminology; and to provide for exchange of information.

The review of methods of examination is accomplished by panels composed of outstanding specialists. When a panel report is approved it becomes a Preliminary Recommendation which is then referred to member organizations. After review and study by member organizations the Preliminary Recommendation, including approved revisions, is issued by JCUMWE as an Official Recommendation.

Official Recommendations

Official Recommendations have been approved by JCUMWE for reporting of results, total hardness, iron, organic nitrogen, grease and oily matter, solids, and manganese (approved but not yet released).

Preliminary Recommendations

Preliminary Recommendations, including those approved during the past year, are under review by member organizations for sulfate, uniformity of reagents, acidity, and alkalinity.

Thirteen panels were active during the past year covering methods of examination for ammonia; calcium and magnesium; carbonate, bicarbonate, and carbon dixoide; chemical oxygen demand; chloride; dissolved oxygen; electrical conductivity; fluoride; lead; odor; pH-glass electrode; total phosphorus; and turbidity.

Four panels were previously authorized but not activated as of March, 1961, for chlorine residual, chromium, nitrite, and silica. New panels were authorized for nitrate and biochemical oxygen demand.

Work was completed on revision of JCUMWE Regulations which will be distributed to member organizations.

The following organizations are members of JCUMWE: AOAC, ASTM, AWWA, API, APHA, ASME, MCA, TAPPI, USGS, USP, USPHS, and WPCF.

ISA-TAPPI Symposium on Pulp and Paper Instrumentation

The ISA-TAPPI Symposium on Pulp and Paper Instrumentation was held May 10–12, 1961, at the Northland Hotel in Green Bay, Wis. The meeting was attended by 230 people from 20 states and Canada.

The program, shown below, was well attended with fine participation by the registrants in the several discussions.

The keynote address was delivered by Ward Harrison, president, Allied Paper Co., Kalamazoo, Mich., and former president of TAPPI.

Dr. Harrison spoke about "professionalism" and listed several meaningful traits among which were: (1) honesty, (2) enthusiasm, (3) loyalty, (4) confidence, (5) stick-to-itiveness, (6) willingness to try—right now, (7) flexibility and an open mind, and (8) pride of profession.

He continued by stating that professionalism, cast against the backdrop of present-day economic, social, and national problems, is not a luxury but a necessity. He further declared that what one does and how he operates as a man has an impact far beyond the ebb and flow of one's immediate personal gain and that the future of each engineer was as bright as he made his profession—*professional*.

The banquet address, by L. R. Thiesmeyer, president, Pulp and Paper Research Institute of Canada, Montreal, Que., was a high point of interest during the Symposium. Dr. Thiesmeyer dwelt on various aspects of the pulp and paper industry and revealed ideas currently under develop-

W. D. Harrison, Allied Paper Co.

L. R. Thiesmeyer, Pulp & Paper Research Institute of Canada

ment which, with the assistance of appropriate instrumentation, could result in drastic changes in the technology of pulp and papermaking. He concluded his remarks with the comment that human beings were the most completely automated, fully instrumented complexes which could be produced with unskilled labor.

Apart from the technical program, instrumentation maintenance clinics were held both Friday and Saturday, May 12 and 13. These clinics were attended by a total of 67 people.

This symposium was sponsored jointly by the Instrument Society of America and by the Technical Association of the Pulp and Paper Industry.

G. G. M. Eastwood, Kimberly-Clark Corp., Neenah, Wis., was the general chairman of the Symposium and his committee was as follows:

Secretary—P. M. Gieseler, Charmin Paper Products Co., Green Bay, Wis.
Finance—H. O. Teeple (treasurer), TAPPI, New York, N. Y.; H. S. Kindler, ISA, Pittsburgh, Pa.
ISA Section Host—P. M. Giesler, Charmin Paper Products Co., Green Bay, Wis.
TAPPI Section Host—R. L. Leaf, Shawano Paper Mills, Shawano, Wis.
Technical Program—J. W. Replogle, Jr. (for ISA), Panellit Service Corp., Skokie, Ill.; C. D. Lindwall (for TAPPI), Marathon Div., American Can Co., Menasha, Wis.
Documentation—H. S. Kindler, ISA, Pittsburgh, Pa.
Publicity—H. O. Teeple, TAPPI, New York, N. Y.
Local Publicity—D. Johnson, Mason, Neilan Co., Appleton, Wis.

Process Instrumentation Committee

General Session: C. D. Lindwall, R. A. Walsh, S. H. Watkins, and R. H. Zielske

ISA-TAPPI Symposium speakers

Panel—Comparison of Instrumentation Systems: C. D. Lindwall, J. R. Warren, R. R. Newton, Jr., and J. W. Replogle, Jr.

Panel—Mill Instrument Education: J. W. Replogle, Jr., J. E. Overall, E. Taibl, G. Weiss, and E. J. Minnar

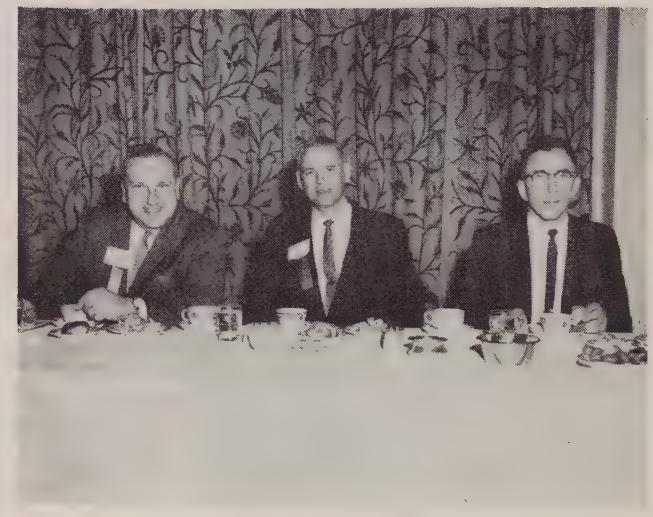
Panel—Application of Computer Control in the Pulp and Paper Industry: L. W. Zabel, C. E. McCarty, E. F. Thode, and K. I. Mumme

At the head table during the banquet at the ISA-TAPPI Symposium on Pulp and Paper Instrumentation

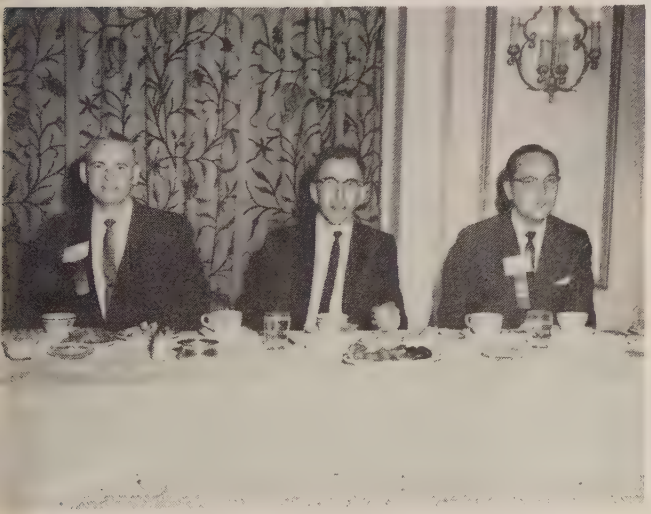
J. W. Replogle, Jr., D. J. Morrissey, and J. C. Wollage

E. W. Prince, E. J. Minnar, and W. R. Nelson

E. F. Thode, M. A. Schreiner, and J. R. Restle



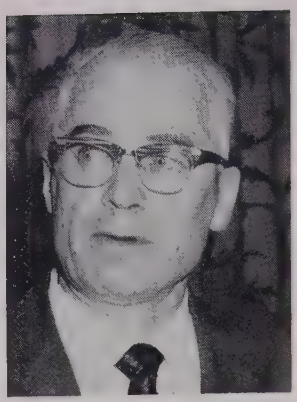
P. M. Giesler, C. D. Lindwall, and E. Kehoe



D. D. Lindwall, E. Kehoe, and H. O. Teeple

ISA-TAPPI Symposium Committee—standing: E. Kehoe, E. W. Prince, M. A. Schreinier, D. J. Morrissey, and D. B. Johnson. Seated: C. D. Lindwall, J. W. Replogle, Jr., G. G. M. Eastwood, P. M. Giesler, and J. R. Nestle

J. C. Wollage, Vice-president, TAPPI



G. G. M. Eastwood, ISA-TAPPI Symposium chairman

W. R. Nelson, chairman, Lake States Section

B. K. Legerwood

Registration—J. Restle, Appleton Coated Paper Co., Appleton, Wis.
Hospitality—W. R. Nelson, Green Bay Pulp & Paper Co., Green Bay, Wis.
Hotel Arrangements—M. Schreiner, Foxboro Co.
Printing—H. O. Teeple, TAPPI, New York, N. Y.
Clinic—E. Kehoe, Marathon Div., American Can Co., Menasha, Wis.; L. Clouse, Kimberly-Clark Co., Neenah, Wis.

Extra copies of symposium reprints are available at $5.00 per copy. The reprints consist of the following:

1. "The Road to Making Money with Automatic Systems," by B. K. Legerwood, *Control Engineering*, New York, N. Y.
2. "Precision Draw-Speed Recording for Paper Machines," by Y. Miyazaki, Tokyo Shibauna Electric Co., Ltd., Tokyo, Japan
3 "pH, An Important Variable in Papermaking," by S. H. Watkins, Hercules Powder Co., Wilmington, Del.
4. "Continuous Percentage Stock Blending," by R. H. Zielske and D. B. Serivens, Taylor Instrument Cos., Rochester, N. Y.
5. "Cost Comparison of Various Instrumentation Systems," by R. R. Newton, Jr., J. E. Sirrine Co., Greenville, S. C.

Reprints may be ordered by writing to either of the following addresses:

H. S. Kindler, ISA, 530 William Penn Place, Pittsburgh 19, Pa.
H. O. Teeple, TAPPI, 360 Lexington Ave., New York 17, N. Y.

Standards for Cellulosic Films

ASTM Committee F-2 on Flexible Barrier Materials has formed a Section to promulgate standards for cellulosic films, primarily for packaging uses. Chairman of the new Section is Leon I. Oetzel, chief control chemist of Milprint, Inc. The section is a part of Subcommittee IV on Specifications whose chairman is Paul Cope of Procter & Gamble. The organization meeting of the new section will be held in conjunction with the next semiannual meeting of F-2 at the Quartermaster Research & Engineering Command, Natick, Mass., on Sept. 26–27, 1961.

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TAPPI NOTES

TAPPI's Divisions and Committees

THIS ISSUE carries the roster of the roughly 1550 TAPPI members currently serving on the Association's eight technical divisions and their 66 committees. The roster, which appears regularly in each edition of the *TAPPI Yearbook*, is being published now in *Tappi* to provide up-to-date information on the committee members, their companies, and their mailing addresses.

The appearance of this roster provides a fitting opportunity to recognize gratefully the invaluable service these committees are performing for the Association. The productivity of these voluntary technical committees constitutes one of the most tangible benefits of the Association to its members and to the industry. Service in the committee organization is entirely voluntary and without financial remuneration. In accepting appointment to these committees the members assume the responsibility of giving freely of their personal time to TAPPI affairs. Without the enthusiastic participation of these committee members and the generous support of their companies TAPPI could not exist. These men are TAPPI's life blood.

Technical committees have played an essential role in TAPPI since its founding in 1915. Many committees in operation today were organized in the early years of the Association's history. At first these committees operated as independent units, but in 1930 M. A. Krimmel, then TAPPI president, grouped committees with related interests into divisions to simplify their administration.

As new areas of technology have developed, existing committees have broadened their scopes or new committees have been established to meet these needs. Within the last twelve months, for example, the Extrusion Coating Committee, the Operations Research Committee, the Release Papers Testing Committee, and the Synthetic Fibers Committee have been created.

At present there are eight technical divisions, each covering a broad area of technology and comprising a number of committees whose scopes of activities are interrelated. Each committee concerns itself with improving the industry's technology in a specific field. The committees are currently engaged in over 350 active programs, which include:

1. The planning and staging of TAPPI's functional conferences and the technical sessions of its annual meetings.
2. The preparation and presentation of technical papers at these conferences and annual meetings. These papers represent two-thirds of all the manuscripts published in *Tappi*.
3. The writing of TAPPI Monographs and Special Reports.
4. The continuing development of TAPPI Standard Testing Procedures, Routine Control Methods, and Technical Information Sheets.
5. The development and supervision of TAPPI-sponsored projects at various universities and other technical institutions.
6. The collection and interchange of technical information through committee meetings, plant visits, mill surveys, and correspondence.

The contributions these programs have made to the technical advancement of the industry are now widely recognized. Appreciation of these benefits by industry management has enable TAPPI members to participate actively in committee projects and to attend committee functions.

But what does the individual member receive for his services to the committee? This is a difficult question to answer, partly because the benefits are frequently intangible, and partly because they are rarely the same for all committee members. Nevertheless many typical advantages can be described.

The returns in mental development, in continuing education in the industry's problems, and in the broadening of personal horizons cannot be stressed too heavily. Experiences of this kind are invaluable in developing leadership ability. Frequently this experience aids in preparing the individual for promotion within his own company. Recognition in his own organization, in the industry, and in government or professional circles is one of the intangible benefits resulting from committee service.

Some members enjoy the opportunities thus provided to enlarge their circle of friends. They find satisfaction in the close association with others outside their own company but sharing the same professional interests and goals. Lasting friendships can frequently be traced to participation in committee service.

Other members recognize a personal responsibility to do their share in advancing the welfare of the industry as a whole. Top management in many companies encourages its personnel to participate actively in Association affairs, so that they will fulfill the role of "good citizens" in the industry. Many members realize that they can contribute most effectively to the advancement of the industry through the work of a technical society. They can guide the policies of the society in a manner which will serve not only their own companies, but the industry and the public welfare as well.

In TAPPI there are roughly 1550 members who are extending their professional horizons by serving on various technical committees. They have many motivations, but perhaps one point deserves special emphasis—namely, that these activities are not done for altruism alone, but also to broaden the professional horizons of the men who engage in them.

P. E. NETHERCUT

TAPPI PROFILES

W. Phalti Lawrence

W. PHALTI LAWRENCE, member of the Executive Committee of the Association, is director of material usage for the Champion Paper and Fibre Co., Hamilton, Ohio.

He was born in 1909 in the town of Elon College, N. C., where his father was Professor of English at Elon College. He graduated from Elon College with a B.A., in 1929, and from North Carolina State College with a B.S. in chemical engineering, in 1930. In his senior year at Elon College he was class president and valedictorian. During the summer months he turned to banking, which he found to be a refreshing occupation, and worked in banks in Greensboro and Burlington, N. C.

On graduating from North Carolina State he joined Champion in Canton, N. C., as a research chemist—a career in the paper industry having appealed to him after he visited Champion on an inspection trip while he was still a college senior. In 1949, Champion's pulp activities were transferred to Hamilton, Ohio, and he went there as assistant director of general research in charge of pulp. His research on pulping, bleaching, and pulping by-products enabled him to publish papers on the collection of sulfate turpentine and on chlorite bleaching of southern pine kraft pulp. In 1958 he became head of the research and development department at Hamilton. Recently, in April, 1961, he was made director of material usage at Champion, and is concerned with the conservation of materials, the development of new material usages, and the correlative coordination of air and stream pollution.

Champion can claim a number of firsts in its history: the company was first (1919) to make commercial bleached pulp from southern pine, using $CaClO_2$, and a few years later installed an electrolytic plant with Champion-designed cells to produce chlorine, which was subsequently used for pulp bleaching. It also pioneered the commercial production of cast-coated paper.

Mr. Lawrence has been a member of TAPPI since 1932. He served on the Alkaline Pulping Committee for 21 years (1932–53). While on the committee he conducted a survey on sulfate turpentine production in the United States (1938), and other surveys on sulfate operations which led to developments and revisions in TAPPI Operating Data Sheets.

The growing interest in pulping by-products gave him the opportunity of establishing the Chemical Products Committee (1947), on which he served as chairman and also as program chairman for the first full technical program sponsored by the committee.

As chairman of the APPA Committee on Coordination of Research Mr. Lawrence and others conducted a series of industry-research institution meetings, which now have evolved into the annual APPA-TAPPI Research Conferences. He is especially interested in improving the technological status of the paper industry by presenting a better image of the industry to the academic world.

In addition to TAPPI, he is a member of the American Chemical Society and the Forest Products Research Society. In 1956 he attended the Advanced Management Program of the Harvard Business School.

In his community he is an elder of the Presbyterian Church and has recently been named to head the Southwest Ohio Science Show for 1961. He is a member of the Kiwanis Club, the Hamilton City Club, and the Elks Country Club. His hobbies are golf, bridge, and photography.

Mr. Lawrence and his wife, Ruth, live in Hamilton, Ohio. Their son, David, himself the father of two children, is a premedical student at Miami University, Oxford, Ohio.

PERSONAL MENTION

New TAPPI Members

Barnwell, Carroll Smith, Manager, Research and Development, Bibb Manufacturing Co., Macon, Ga., a 1949 graduate of Clemson Agricultural & Mechanical College.

Blackford, John M., Vice-President, Hosmer Machine Co., Contoocook, N. H., a 1951 graduate of Purdue University.

Boll, Richard L., Sales Engineer, John W. Bolton & Sons, Inc., Lawrence, Mass., a 1939 graduate of University of Southern California.

Bowen, Richard L., Jr., President and Treasurer, Coated Textile Mills, Inc., Pawtucket, R. I., a 1941 graduate of Princeton University, with a Sc.D. degree in 1949 from Massachusetts Institute of Technology.

Brafford, Donald A., Senior Research Engineer, Beloit Iron Works, Beloit, Wis., a 1937 graduate of Purdue University.

Breeden, William J., Mill Superintendent, Bowater-Scott Corp., Ltd., London, England.

Brookfield, Donald W., Research Director, Brookfield Engineering Labs., Stoughton, Mass., a 1933 graduate of Massachusetts Institute of Technology.

Brown, David O., Sales, Borden Chemical Co., New York, N. Y., a 1949 graduate of Lehigh University.

Bruschi, Romano, Production Control Manager, Corriere Della Sera, Milano, Italy, graduate of University of Bologna.

Bulger, William H., Chief Engineer, Hydraulic Machinery Co., Ltd., Montreal, Que., a 1950 graduate of University of Saskatchewan.

Bullen, John D., Plastics Technologist, Ciba (ARL), Ltd., Cambridge, England, a 1961 graduate of National College of Rubber Technology.

Cash, Carson D., Sales Engineer, Beloit Eastern Corp., Downingtown, Pa., a 1951 graduate of Clemsen Agricultural & Mechanical College.

Castellanos G., Juan M., Managing Director, Polimeros Industriales, S.A., Bilbao, Spain, a 1951 graduate of Escuela Ingenieros Industriales.

Chene, Marcel, Professor, Ecole Francaise de Papeterie, Grenoble, Isere, France, a 1961 graduate of Ecole Normale de la Savoie et Lycee de Lyon.

Churchill, Roy K., Technical Superintendent, Nova Scotia Pulp, Ltd., Port Hawkesbury, Nova Scotia, a 1950 graduate of Nova Scotia Technical College.

Cohen, Irvin G., Chemist, Arkwright Finishing Div., Interlaken, Inc., Fiskeville, R. I., a 1957 graduate of Hofstra College.

Crane, Lawrence P., Technical Assistant, Oxford Paper Co., Inc., Lawrence, Mass., a 1952 graduate of Northeastern University.

Currie, Donald C., Mill Manager, Howard Smith Paper Mills, Ltd., Beauharnois, Que., a 1928 graduate of University of New Brunswick.

Eegerdingk, Wybo, Chemical Engineer, N.V. Stijfsel en Glucosefabriek 'Sas Van Gent,' Sas Van Gent, Holland, a 1952 graduate of Technical High School, Delft.

Erdelbrock, Harold W., Superintendent, Washington Pulp & Timber Co., Longview, Wash.

Evans, Woodrow W., Development Engineer, St. Regis Paper Co., Pensacola, Fla., a 1955 graduate of University of Alabama.

Fisher, Marshall H., Librarian, Technological Institute Library, Northwestern University, Evanston, Ill.

Fritzsching, Peter R., Paper Mill Representative, Penick & Ford Ltd., Inc., New York, N. Y. Attended University of Heidelburg, Germany.

Gerbaux, Rene C., Director, Research & Development, Societe Industrielle De La Cellulose, Ghent, Belgium, a graduate of University of Louvain.

Graham, Joseph T., Tutor Librarian, Watford Technical College, Watford, Hertfordshire, England, a 1952 graduate of Newcastle Municipal College of Commerce.

Gupta, Subir, Project Assistant, Balmer Lawrie & Co., Ltd., Calcutta, India, a 1952 graduate of University of Calcutta.

Hadert, Hans F., Editor, Hadert-Lexikon-Verlag, Berlin, Germany.

Hannah, Robert W., Research Chemist, Aluminum Co. of America, Alcoa Research Labs., New Kensington, Pa., a 1953 graduate of Niagara University.

Hedlud, Torne, Engineer, George Bolle AB, Stockholm, Sweden.

Hogberg, Torkel, Chief Engineer, Skanska, AB, Perstrop, Sweden, a 1954 graduate of Royal Institute of Technology, Stockholm.

Hough, Ronald B., District Technician, Kelco Co., Clark, N. J., a 1960 graduate of University of Alabama.

Howley, Thomas B., Manager, Stearate Industry Div., Nuodex Products Div., Heyden Newport Chemical Corp., Elizabeth, N. J., a 1949 graduate of La Salle College.

Irvine, James B., Process Engineer, Quaker Chemical Products Corp., Conshohocken, Pa., a 1937 graduate of University of Kentucky.

Leete, Stuart F., District Manager, Pulp & Paper, San Francisco, Calif., a 1927 graduate of Stanford University.

Lorenc, Jaroslav, Reference Librarian, John Lysaght (Australia), Ltd., Newcastle, N.S.W., Australia.

Maheshwari, Ram Lal, Mechanical Engineer, West Coast Paper Mills, Ltd., Dandeli, India, a 1952 graduate of College of Engineering.

Marton, Joseph, Research Chemist, West Virginia Pulp & Paper Co., Charleston, S. C., a 1943 graduate of University of Pazmany Peter.

Mullen, Benjamin J., Salesman, Bristol Metal Products Corp., Bristol, Tenn.

Olsson, Ingvar, Chief Engineer, AB Nordstroms Linbanor, Stockholm, Sweden, a 1930 graduate of Orebro Technical College.

Park, Leonard, Manager, Technical Services, Inter City Papers, Ltd., Montreal, Que., a 1948 graduate of McGill University.

Partansky, Alexander M., Research Group Leader, Dow Chemical Co., Pittsburg, Calif., a 1935 graduate of University of Washington.

Patton, William R., Project Engineer, International Paper Co., Pine Bluff, Ark., a 1958 graduate of University of Houston.

Raffin, Antonio L., Pulp Mill Superintendent, Champion Celulose S.A., Sao Paulo, Brazil, a 1949 graduate of University Rio Grande do Sul.

Roden, Monte C., Chemist, Washington Pulp & Timber Co., Longview, Wash., a 1959 graduate of Lower Columbia Jr. College.

Roos, John H., Application Engineer, General Electric Co., Schenectady, N. Y., a 1956 graduate of University of Washington.

Rustia, Ramon M., Editor, Reproduction Methods for Business & Industry, New York, N. Y., a 1956 graduate of Dartmouth College.

Savage, Donald W., Manager, Production Engineering Div., Wiggins Teape Group Management, Ltd., London, England, a 1946 graduate of Christ's College, Cambridge.

Schweger, Boyd B., Chief Engineer, Fort Howard Paper Co., Green Bay, Wis., attended Lawrence College, and Armour Institute of Technology.

Sormanto, Klaus O., Technical Manager, Enso-Gutzeit Osakeyhtio, Vuoksenniska, Finland, a graduate of Technical Institute of Finland.

Sykes, Jacquelin D., Research Librarian, Polaroid Corp., Cambridge, Mass., a 1935 graduate of University of Connecticut.

Webb, Maysie, Librarian, Patent Office Library, London, England.

Wells, Roger, Research Engineer, Diamond National Corp., Stamford, Conn., a 1943 graduate of New York State College of Forestry.

Wiggins, Robert B., Superintendent of Maintenance, Fort Howard Paper Co., Green Bay, Wis., attended Marquette University.

Willink, Nicholas W., Trainee, Janes Cropper & Co., Ltd., Kendal, England, a 1959 graduate of Cambridge University.

Young, John C., Salesman, Borden Chemical Co., New York, N. Y., a 1950 graduate of Kenyon College.

Appointments

Thomas Aitken, formerly with West Virginia Pulp & Paper Co. is now a research chemist for Nalco Chemical Co., Chicago, Ill.

Lyman C. Aldrich, formerly of St. Regis Paper Co., is now Senior Research Chemist for Mosinee Paper Mills, Mosinee, Wis.

Louis O. Barber, formerly of Austill Waxed Paper Co., is now Printing Supervisor of Zimmer Paper Products, Inc., Indianapolis, Ind.

Clyde A. Benson, formerly of Mead Corp., is now a consultant for papermaking and converting at 2 Herrick Drive, Old Tappan, N. J.

Robert W. Birch, formerly of West Virginia Pulp & Paper Co., is now Quality Control Engineer for the Peter J. Schweitzer Division, Kimberly-Clark Corp., Lee, Mass.

Henry A. Birdsall, formerly of the Bell Telephone Laboratories, Inc., is now an engineer for the American Telephone & Telegraph Co., New York, N. Y.

Walter C. Bloomquist of the General Electric Co., has been transferred from Philadelphia, Pa., to Schenectady, N. Y., as Manager of Industrial Power Operation.

Duane H. Bond, formerly of Owens-Illinois Glass Co., is now Director of Technical Service of Goodrich-Gulf Chemicals, Inc., Cleveland, Ohio.

John P. Bosshardt is now Superintendent of Mead Containers, Atlanta, Ga.

Robert N. Brownlee, formerly of Personal Products Corp., is now chemical engineer for St. Regis Paper Co., Dallas, Tex.

Ralph W. Buttery is now Director of Manufacturing for Bathurst Containers, Ltd., Montreal, Que.

Preston D. Carter is now Special Assistant to the Executive Vice-President of KVP-Sutherland Paper Co., Kalamazoo, Mich.

George T. Cartier, formerly of A. M. Collins Mfg. Co. Division in now a consulting chemist in webb processing in Wayne, Pa.

Louis P. Cartsunis of the Becco Chemical Division has been transferred from Buffalo, N. Y., to the Princeton, N. J., Central Research Laboratory of Food Machinery & Chemical Corp.

John S. Cheriton, formerly of Abitibi Power & Paper Co., is now Production Superintendent for Irving Pulp & Paper, Ltd., Lancaster, N. B.

Howard B. Church, formerly of A. M. Byers & Co., is now a sales engineer for the Water Service Laboratories, Inc., New York, N. Y.

Richard S. Clark of Hercules Powder Co., has been transferred from New York, N. Y., to San Francisco, Calif., as District Manager.

Edgar R. Comee is now Resident Vice-President and General Manager of the Pejepscot Paper Co., Brunswick, Me.

Ray H. Cross, formerly of St. Regis Paper Co., is now an engineer with Improved Machinery, Inc., Nashua, N. H.

Charles W. Davidson is now Supervisor of Product Quality and Development of Crown Zellerbach Corp., Camas, Wash.

George F. De Long is now Technical Superintendent of Hinde & Dauch of Canada, Toronto, Ont.

John T. Flis is now Plant Manager of Keasbey & Mattison Co., Perth Amboy, N. J.

Frederick R. Gardner, formerly of Hinde & Dauch of Canada is now with the Hawley-Monk Co., Cincinnati, Ohio.

Victor Gilpin, formerly of Trinity College is now in the Department of Chemistry of the University of Wichita, Kan.

Gary E. Greene of Firestone Tire & Rubber Co., has been transferred from Magnolia, Ark., to Fall River, Mass., as a chemist.

William D. Hall has retired as Research Director of the Folding Paper Box Association of America, Chicago, Ill.

Frederick E. Hertha is now Director of Planning for Columbia Cellulose Co., Ltd., Vancouver, B. C., Canada.

James J. Higgins, development chemist for Ohio Box Board Co., has been transferred from Rittman, Ohio, to Grand Rapids, Mich., plant of Packaging Corp. of America.

William H. Holl, formerly of Riegel Paper Corp., is now Vice-President in Charge of Manufacturing of Patrician Paper Co., So. Glens Falls, N. Y.

David S. Hollingsworth is now Assistant Sales Manager for Paper Chemical Specialties of Hercules Powder Co., Wilmington, Del.

Gunther Hunger, formerly of the Institute for Cellulose Chemistry, Darmstadt, Germany, is now with the West Virginia Pulp & Paper Co., Luke, Md.

John F. McInnis, formerly Assistant Chief Engineer for Bowaters Research & Development, Inc., is now with Tasman Pulp & Paper Co., Ltd., Kawerau, Bay of Plenty, New Zealand.

Diptendra N. Mitra, formerly of Lyddon & Co., Ltd., is now a project engineer with Millspaugh-Wimpey, Ltd., London, W. 6, England.

Kenneth R. Moehl is now Vice-President of Simplex Paper Co., Adrian, Mich.

H. Walter Moeller, formerly of National Starch & Chemical Co., is now Packaging Materials Manager for Packaging Frontiers, Inc., Waltham, Mass.

George A. T. Moore is now Manager of Paper Industry Sales for A. E. Staley Mfg. Co., Decatur, Ill.

William R. Morrison of International Paper Co., has been transferred from Philadelphia, Pa., to New York, N. Y., as a sales specialist.

Ralph D. Mosher, formerly Assistant Bleach Plant Superintendent for the Minnesota & Ontario Paper Co.,

is now with Ontario-Minnesota Pulp & Paper Co., Ltd., Kenora, Ont.

William R. Moulton, formerly of West Virginia Pulp & Paper Co., is now a production engineer for John W. Bolton & Sons, Inc., Lawrence, Mass.

Francis C. Mudge, formerly Manager of Wheat Industries (Australia) Pty., Ltd., is now with Geo. Fielder & Co., Ltd., Sydney, N.S.W., Australia.

John P. Munton, formerly of Rice Barton Corp., is now Chief Engineer for the Roy Smythe Co., Portland, Ore.

Ralph F. Patterson is now General Manager in Charge of Research and Planning for MacMillan, Bloedel & Powell River, Ltd., Vancouver, B. C., Canada.

James B. Pickering, formerly of Chemical Paper Mfg. Co., is now Plant Superintendent of the United Board & Carton Corp., Thomson Broad Division, Thomson, N. Y.

Ralph B. Quelos is now General Sales Manager for pigments and colors for the Glidden Co., Baltimore, Md.

Robert W. Ramsdell of Hercules Powder Co., has been transferred from Wilmington, Del., to Milwaukee, Wis., as a technical representative.

James C. Rankin is now General Sales Manager for Metals and Organic Chemicals for the Glidden Co., Cleveland, Ohio.

James Rogers II is now a staff consultant to the Sandy Hill Iron & Brass Works, Hudson Falls, N. Y.

Charles E. Roth, formerly of Champion Paper & Fibre Co., is now an administrative coordinator for Bowaters-Carolina Corp., Catawba, S. C.

I. Bruce Sanborn, formerly a student at The Institute of Paper Chemistry is now Assistant Director of Corporate Planning and Development for Consolidated Water Power & Paper Co., Wisconsin Rapids, Wis.

James A. Sargent of the Container Laboratories, Inc., has been transferred from Chicago, Ill., to Los Angeles, Calif., as Technical Director.

Chester J. Schmidt has retired as Vice-President of J. O. Ross Engineering Corp., New York, N. Y.

Alan M. Schwartz, formerly of Connecticut Container Corp., is now Quality Control Engineer for Interstate Container Corp., Glendale, N. Y.

William H. Somers, formerly of Dow Chemical Co., is now a technical sales representative for Minerals & Chemicals Philipp Corp., Kalamazoo, Mich.

Richard W. Van Duyne, formerly of West Virginia Pulp & Paper Co., is now an engineer with International Business Machines Corp., White Plains, N. Y.

Robert J. Van Nostrand, formerly of the Brown Co., is now President of the Merrimac Paper Co., Inc., Lawrence, Mass.

Herman W. Verseput, formerly of Robert Gair Co., is now Manager of Folding Carton Development for Riegel Paper Corp., Milford, N. J.

Hermann Weiss, formerly of St. Regis Paper Co., is now a development engineer for West Virginia Pulp & Paper Co., Covington, Va.

Pauli O. Wendelin, of West Virginia Pulp & Paper Co., has been transferred from Covington, Va., to Charleston, S. C., as a research chemist.

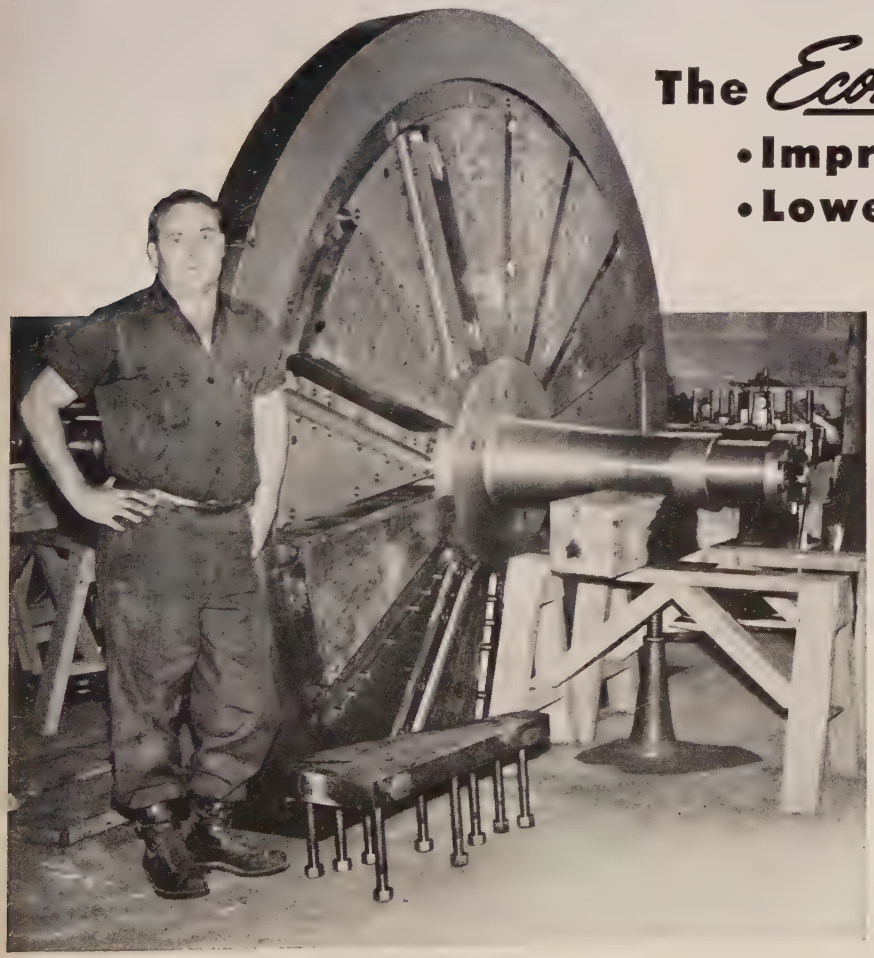
Albert P. Yundt is now Director of Research for Bird & Son, E. Walpole, Mass.

* * *

John M. McEwen has succeeded **Harold W. Bialkowsky** as the official corporate representative of Weyerhaeuser Co., in the Technical Association.

* * *

George A. T. Moore, Manager of Paper Industry Sales has succeeded **R. L. Schuerman** as the official representative of A. E. Staley Mfg. Co., Decatur, Ill., in TAPPI.



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INDUSTRY NOTES

Paper Manufacturers and Converters

ABITIBI POWER & PAPER CO., LTD.

A new and economic process for base recovery from spent sulfite liquor was revealed by Abitibi Power and Paper Co., Ltd. and Pfaudler Permutit Inc. at the June 7–9 meeting of the Technical Section of the Canadian Pulp and Paper Association at Saranac Lake, N. Y. Unlike earlier ion exchange processes, none of which has won acceptance, the Abitibi-Permutit ion exchange process has been demonstrated in a 1 ton pulp per day pilot plant to be technically and economically successful.

The process uses Permutit Q cation exchange to adsorb base from spent sulfite liquor and sulfur dioxide elution to recover the base in concentrations that can be effectively and efficiently used in the normal pulping cycle. Key to the success of the process is the development of special operating techniques that result in over 80% base recovery and usable reconstituted cooking liquor without spent liquor evaporation.

The estimated investment and operating costs are low and attractive. A payout time in the range of three years is possible for medium sized mills.

CONSOLIDATED WATER POWER & PAPER CO.

Consolidated Water Power & Paper Co. recently announced it is shutting down its experimental spent sulfite liquor recovery plant in Wisconsin Rapids on May 27 after a commercial-scale test run that lasted 3 years and cost more than $1 million.

The experimental recovery plant was built by Consolidated at an investment of $750,000 to test operating efficiency and actual costs of a new Western Precipitation process for recovering and re-using chemicals and heat from sulfite liquor, thus preventing discharge of this pulping by-product into the Wisconsin River. After completing three years of scheduled operation, adequate experience and technical data have been accumulated for full analysis of this process.

In the next several months a decision on the recovery plant's proper place in the company's future stream improvement program, should be reached.

During the shutdown spent sulfite liquor from the Wisconsin Rapids pulp mill will be disposed of through a soil filtration lagoon. Consolidated will continue uninterrupted operation of the Appleton utilization plant that since 1953 has evaporated spent sulfite liquor from the company's pulp mill on the Fox River for conversion into lignin liquor products or for burning as industrial fuel.

Staff

I. Bruce Sanborn has joined Consolidated Water Power & Paper Co., it has been announced by G. K. Dickerman, director of Corporate Planning and Development. He will serve as assistant to Mr. Dickerman.

DIAMOND NATIONAL CORP.

William H. Walters, chairman and president of Diamond National Corp., announced that the company will build a molded-pulp plant in West Germany. The plant, to be operated by Diamond's West German subsidiary, Omni-Pac G.m.b.H., will be located at Elsfleth, 18 miles north of Bremen in Lower Saxony. The plant will be the first of its kind in Germany and will produce a diversified line of molded pulp products to meet the growing demand on the Continent for prepackaged foods.

E. T. Gardner, Jr., vice-president in charge of Diamond's foreign department, will direct the West German program, along with the company's other foreign operations. Construction and equipping of the new German plant will be done in two phases, the first of which will represent an investment of more than $6,000,000. Major production equipment for the project has been designed by the Diamond National engineering department and will be built in the United States.

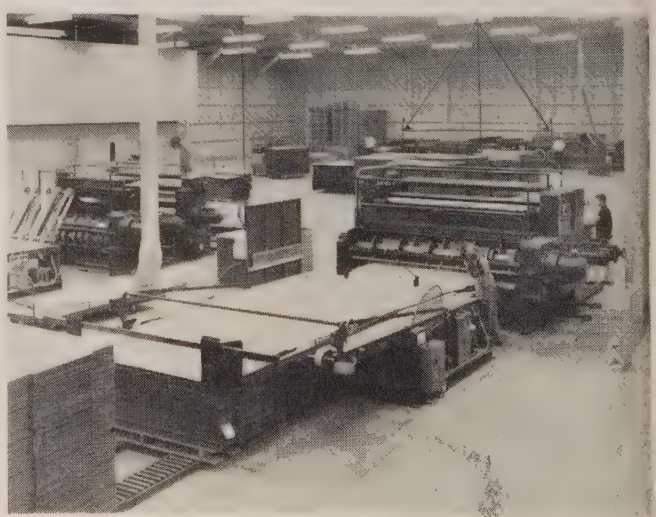
H. G. Brandes has been appointed general manager of Omni-Pac and will assume responsibility for the operation of the new plant. German personnel will be recruited and will be trained in the United States.

GEORGIA-PACIFIC PAPER CO.

Georgia-Pacific Paper Co. officially opened its new container division plant at Olympia, Wash., May 26 and 27. The

Exterior view of Georgia-Pacific Paper Co.'s new container division plant at Olympia, Wash., officially opened with ceremonies May 26 and 27. The structure is built of plywood and lumber bought from the parent corporation and covers 126,000 sq. ft. It is automated, has covered loading for rail and truck transport, plus quick access to deep water port facilities

division's machinery will run single or double-wall board in a variety of components to satisfy all known box making



New Scott towel cartons roll through printer-slotter machine in Georgia-Pacific Paper Co.'s new container division

requirements. Controlled specified containerboard will be supplied from Georgia-Pacific Paper Co.'s Toledo, Ore., mills. Printing equipment in the plant is capable of handling the full range of box sizes. In addition to standard stitching and taping machines, the facility has a folder-gluer to meet the increasing demand for glued joints.

Kimberly-Clark Corp.

Denis A. Kitchen, Jr., of Kenmore, N. Y., and **William Davis, Jr.,** of Levittown, N. Y., have been awarded Kimberly-Clark Corp. scholarships for the study of printing management at Rochester Institute of Technology. Mr. Kitchen will receive a $400 a year grant and Mr. Davis will receive $500 for four years of study at the New York school.

The Kimberly-Clark scholarships are granted under the auspices of the National Scholarship Trust Fund for the Printing and Publishing Industry, Washington, D. C. They are awarded on the basis of a national examination conducted by the Educational Testing Service, Princeton, N. J. Some 200 high school students took the examination this year.

Mead Corp.

Research Center

The Mead Corp. Research Center, employing 200 scientists and technicians, is located at Chillicothe, Ohio, which is the largest center for the manufacture of fine white paper in the world.

The laboratories located in the Research Center are equipped to perform many functions in paper research and substantially all functions in applied research for this industry including:

1. The manufacture of paper experimentally from almost any material which in its natural form consists of fibers or can be made into fibers, such as aluminum, glass, ceramics, and certain plastics.
2. Formulating new combinations of paper and plastic materials, thus opening up new markets for new paper products.
3. Developing methods of increasing paper machine speed—increasing paper production.
4. Measuring the electrical properties of new grades of paper.
5. Identifying all the elements of air pollution resulting from the papermaking process, determining the concentration at which air pollution can be detected and developing methods of neutralizing air pollution elements.
6. Measuring the strength of wood fibers—even the strength of a single wood fiber; wood fibers are the basic ingredient in the papermaking process.

Among the departments at Mead's Research Center is a complete radioactive tracer laboratory believed to have more extensive equipment than any other laboratory in the industry. In this laboratory, any material used in papermaking can be "tagged" with a radioactive element and followed through the manufacturing process. As a result, new light is being shed on the formation of paper on the paper machines by these studies. One of the radioactive materials used is carbon 14, whose radioactivity is less than the "background" radiation, from cosmic rays and other sources, which is present everywhere on earth. Thus, use of carbon 14 does not constitute a danger. Special equipment to shield out the background radiation is required so that the presence of carbon 14 can be detected.

In Mead's photo lab both photomicrography and ultra high-speed photography are used to study papermaking. Some photos show how cellulose fibers are formed into paper; others show what happens to pulp on the paper machine; still others show the stresses on paper as it passed through a printing press. Exposures of $^1/_{1,000,000}$ of a second are common, and in some cases it has been necessary to use exposures of $^1/_{10,000,000}$ of a second to stop fast-moving machinery.

Multipurpose Forming Board

A new kraft-type paper forming board, which can be molded permanently under heat and pressure into the most complex shapes with unbelievable speed, has been developed at the Mead Corp.'s Research Center. The new product, now known as Mead Form-L Board 200, may be less costly than all other asphalt-free forming boards and competitive with some grades of asphalt forming boards.

The product in its present formulation gives good dimensional stability, can be easily printed or coated with a score of finishing materials, can be die-cut or perforated, and tenaciously holds its shape after forming. It does not warp. It differs from asphalt forming board in that it exhibits no cold flow or bleed characteristics.

It will probably be suitable for a host of applications, including automobile interior components such as kick panels, seat side shields, arm rests, door and roof panels, garnish, and sun visors; free form furniture, chair seats, and card table tops; wall panels, window and door frames, and kitchen or book shelves; formed packages for fragile goods, formed luggage shells, gun and instrument cases; toys and novelties; manikins; embossed signs; pallets for material handling; and low-cost, low-voltage substrates for printed circuits.

Nekoosa-Edwards Paper Co.

Summer School Scholarships

Summer school scholarships have been awarded to 26 public school teachers in Port Edwards and Nekoosa by Nekoosa-Edwards Foundation. The awards are based on the length of time in attendance at a summer school and the course of study. An average award covers about 75% of total expenses, excluding travel costs. Teachers studying for advanced degrees receive a larger amount.

The awards are determined by a committee of community residents, none of whom is connected with the foundation. All applications for scholarships are approved by the awards committee provided the course of study is of value to the school system.

A total of 112 scholarships have been awarded since the program was established in 1957.

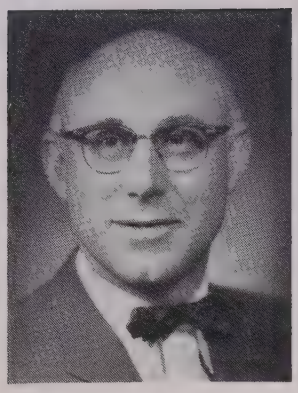
Of the 1961 scholarship recipients, eight teachers will be doing undergraduate work toward a bachelor's degree or toward a specific certification. Two are planning to work toward a doctor's degree while 16 are studying for a master's degree. While most of the group will be attending Wisconsin institutions for summer sessions, six will be studying at out-of-state colleges.

Nicolet Paper Corp.

High-speed aluminum coating of glassine in continuous mill roll lengths under normal mill conditions is being successfully carried out by Nicolet Paper Corp. (a subsidiary of Milprint, Inc.) at West De Pere, Wis., in special vacuum deposition equipment designed and built by F. J. Stokes Corp., Philadelphia, a pioneer in the field of vacuum metallizing procedures.

The aluminum-coated glassine is now being commercially offered by Nicolet in 25 through 50-lb. basis weights, at prices which promise significant reductions in packaging costs. Comparative price estimates show that the 25-lb. material can be used satisfactorily, and at substantial cost-savings, in applications where 0.00035 foil-tissue or foil-sulfite laminations are presently being used, according to a spokesman for Nicolet.

The reflective surface substantially increases the glassine's light-barrier properties, and controlled deadfold characteristics are assured by special plasticizers added to the glassine during its manufacture, which should make the new material an active competitor to aluminum foil.



Lionel A. Cox, Personal Products Corp.

Lowell M. McGinnis, Rayonier, Inc.

The stock is processed at normal mill-moisture content, and requires no special preparation or conditioning before coating.

The Stokes vacuum coating equipment has been built to mill-type standards and is a rugged, dependable unit which has proved that it can stand up to continuous day-in, day-out operation. The chamber, somewhat resembling a large bank-vault, has a full-width, full-opening door at one side, to provide the maximum accessibility for loading and unloading the rolls of stock. This assures rapid turn-around and short processing cycles. The unit will handle rolls up to 40 in. wide and up to a maximum of 36 in. in diameter.

The aluminum is evaporated from an electrically heated "boat," which holds the molten metal at a temperature of 2500°F. The metal-source holds a 10-hr. supply and has been designed for long life without maintenance.

With the roll of uncoated stock in place, the door is closed and the chamber is evacuated to a pressure at which level the aluminum vaporizes in the form of minute droplets. These condense on the paper as it passes swiftly above the "boat" in a microthin coating of pure aluminum with a thickness of $3^1/_2$ millionths of an inch.

Smoothness and luster of the finished product depend on the grade and type of glassine that is being coated. The material is strong, greaseproof, and odor-resistant.

Personal Products Corp.

Personal Products Corp. has named **Lionel A. Cox** vice-president of research and development engineering and a member of the board of directors. Personal Products, an affiliated company of Johnson & Johnson, manufactures sanitary protection products for women.

Rayonier, Inc.

George A. Holt announced that he was resigning his position as resident manager of Rayonier's Grays Harbor division because of ill health, but he would continue his long association with the company as an active consultant in operations. From the company's executive offices at New York, it was simultaneously announced by George E. Scofield, general manager of cellulose operations, that **Lowell M. McGinnis** would assume the position of resident manager, replacing Mr. Holt. Mr. McGinnis' office of assistant resident manager of the large Harbor operation will be filled by **Joseph A. Krauth,** who has been resident engineer. In turn, his post will be assumed by **Lester R. Reekers,** former assistant resident engineer.

Riegel Paper Corp.

Riegel Paper Corp. has announced the appointment of **H. W. Verseput** as manager of Folding Carton Development for the Folding Carton Division. Dr. Verseput will make his headquarters at Riegel's Milford, N. J., laboratories.

St. Regis Paper Co.

St. Regis Paper Co. announces that **George A. Littlefield** has been named general manager of the Panelyte Division. Mr. Littlefield will be responsible for both sales and manufacturing operations of the division.

Stone Container Corp.

The Stone Container Corp. recently announced the successful start-up of the first part of its expanded production facilities at Coshocton, Ohio, which features a new Black-Clawson stock preparation system and a paper machine, housed in its own new building and supplied by the United Paper Machinery Corp. with modernizing components from Black-Clawson's Paper Machine Division. It produces 150 tons a day of 9-pt. semichemical corrugating medium.

New stock preparation equipment in this operation includes a 20-ft. Hydrapulper, Ruffclone, breaker trap, three Liquid Cyclones, two Classifiners, HMSS and HM pumps, a thickener, agitators, a no. 5 Black-Clawson jordan and an automatic continuous pulper for broke handling.

Next in line for start-up is the new pulp mill utilizing Black-Clawson's ChemPreg cold soda system. It will process Ohio hardwoods to produce 150 tons of pulp a day for corrugating medium. Pulp production is scheduled to start in the early summer.

Tennessee River Pulp & Paper Co.

Tennessee River Pulp & Paper Co.'s new 500 tons per day kraft pulp and paper mill at Counce, Tenn., now is in full operation. Located near the Tennessee River and adjacent to T.V.A.'s Pickwick Hydroelectric Dam, the mill is on a split level site of some 1600 acres.

The mill structures were constructed on the upper level of the site with ample provisions made for future expansion. The lower level forms a natural effluent ponding area that allows for controlled disposal of the total effluent.

This location provides many advantages among which are:

1. Unlimited water of good quality drawn from the lake formed by Pickwick Dam.
2. Reliable electric power at a reasonable rate from the T.V.A. system.
3. Adequate supplies of both pine and hardwoods.
4. Shipping by water on the Tennessee, Ohio, and Mississippi Rivers plus direct connection to three main line railways—Illinois Central; Gulf, Mobile and Ohio; and Southern—provided by the Corinth and Counce Railroad.
5. Proximity to natural gas transmission pipeline.

These plus other factors caused the management to select this particular site. The original concept called for a mill to provide 500 tons of kraft linerboard per day of such quality as to maintain a favorable marketing position with its competitors. This concept was adhered to throughout the development with many innovations being applied in achieving the goal as originally visualized.

G. W. E. Nicholson, Tennessee River Pulp & Paper Co.

E. M. Leavitt, Tennessee River Pulp & Paper Co.

Tennessee River Pulp & Paper Co, mill at Counce, Tenn., looking west across fire pond

Some of these innovations include: outside storage of wood in the form of chips rather than logs, use of maximum instrumentation, outside construction of boilers, evaporators, and other equipment, hot stock refining, hot stock screening, and completely remote control of all steps in digesting, refining, screening, and washing.

The executive and management personnel of the company represents many years of experience in the industry with numerous other companies. These groups are:

Board of Directors
- W. Irving Osborne, Jr.
- W. D. P. Carey
- G. W. E. Nicholson
- John L. Bell
- Wayne Young

Executive
- G. W. E. Nicholson, president
- E. M. Leavitt, vice-president and resident manager
- D. W. Maxon, secretary-treasurer

Control and Finance Division
- G. O. Griffith, controller and assistant treasurer
- Harry D. Wilson, chief accountant
- Leon G. Smith, purchasing and traffic manager

Production Division
- R. F. Cuyle, general superintendent
- H. C. Carter, plant engineer
- G. L. Hollimon, pulp mill superintendent
- Frank Jensen, paper mill superintendent
- Francis Hank, assistant pulp mill superintendent, pulping
- J. G. Lee, assistant pulp mill superintendent, power and recovery
- H. L. Lusby, paper manufacturing superintendent
- John Morris, assistant paper mill superintendent
- H. M. Lyle, finishing and coating superintendent
- T. A. Terry, maintenance superintendent
- A. B. Lindsey, instrument supervisor
- H. O. Lovic, chief electrician

Industrial Relations
- D. R. Pichon, Jr., industrial relations director
- James Forrester, safety supervisor

Wood and Land Division
- A. K. Dexter, wood and land manager
- N. W. Sentell, assistant wood and land manager
- W. W. Vickery, forest management superintendent
- W. E. Gibbons, wood procurement superintendent

Technical Division
- J. C. Baumgartner, technical superintendent

The general contractor selected to provide all purchasing, engineering, and construction was the M. W. Kellogg Co. Provision was made in the original contract to provide that the engineering for the project be subcontracted to a consultant acceptable to both the Tennessee River Pulp & Paper Co. and the M. W. Kellogg Co. The two parties agreed that H. A. Simons (International), Ltd. of Vancouver, B. C., would provide the engineering for the plant. Both parties established offices located at Vancouver, British Columbia, Canada, adjacent to H. A. Simons offices for liaison and coordination from the very beginning of design and construction. These offices were maintained until the major engineering was completed.

Most of the operating concepts and equipment applications have been used in part in other mills, but it is believed that this is the first plant to make use of so many somewhat unusual applications in one location. The company can manufacture linerboard of all weights. A hardwood conventional yield secondary sheet can be applied through the secondary headbox with a high yield hot stock refined primary sheet of pine pulp. Two separate pulp systems are used to provide positive control of the two components.

Wood Preparation Department

Wood is received in lengths of 5 ft. 3 in. and diameters up to 22 in., by rail and truck along either side of a metal lined reinforced concrete flume 650 ft. in length. The truck wood is unloaded by means of two cranes and a rail mounted wood rake to the flume for railroad unloading or by crane to temporary ground storage. Water is circulated through the flume by means of two 100 hp., 12,000 g.p.m. vertical pumps that draw the water from twin grit removal pits. These pits are equipped with drag-type continuous grit removal conveyors and rotary trash screens.

The wood is conveyed from the flume to twin barking drums by means of an inclined chain conveyor 140 ft. in length which elevates approximately 40 ft. to the drum inlet chutes. The drums are 12 ft. diam. and $67\frac{1}{2}$ ft. in length, being composed of three sections each. The first two sections are driven by a 150-hp., 900 r.p.m. motor with the final section driven by a 75-hp., 900 r.p.m. motor. The motors are connected to the drums through fluid couplings, belt systems and reduction gears to give a drum speed of 6 r.p.m. The drum surfaces are composed of 36 M bars welded to steel rings. Discharge gates are remotely controlled by pneumatic positioners that automatically maintain the selected position.

The drums discharge into an inclined conveyor made up of four parallel chains that have pick up lugs at 6-ft. intervals. This conveyor passes at 90° to the major axis of the drums and passes the wood to a set of spiked speed rolls that serve to straighten the logs for proper transfer to the sorting belt. The speed rolls cause the sticks of wood to strike a heavy hanging target plate and drop to a short transfer deck made up of seven parallel chains that convey with a 90° change in direction. This transfer deck conveys the wood to the sorting belt which is a flat rubber belt $5\frac{1}{2}$ ft. wide by $25\frac{1}{2}$ ft. long. The belt speed is 90 f.p.m. This conveyor allows the removal of oversize logs. The wood discharges from the sorting belt to the chipper feed belt with a 90° change in direction. The chipper feed belt is 2 ft. wide and $23\frac{1}{2}$ ft.

Composite view—woodyard

long and runs at 350 f.p.m. This belt discharges the wood into the chipper spout.

The chipper is a 12-knife, 104-in. diam. machine with a 23-in. V spout direct connected to a 1250-hp., 360-r.p.m. motor. The back of the disk is equipped with fan blades that blow the chips through a top discharge through a blow line into an elevated surge bin.

Bark from the barking drums plus trash from the flume is conveyed by belts from the bark chutes under the drums to a bark hog that is protected by an electromagnet. The bark is conveyed from the hog by belt and then flight conveyors to a bark storage bin for use as fuel in the combination boiler.

Chip Handling System

The chips are received from the chipper by a surge bin, 16 ft. diam. by 25 ft. high, equipped with a $14^1/_2$ ft. diam. rotating table discharger which delivers the chips into a rotary pocket feeder. This pocket feeder delivers the chips into the blow line of a pneumatic conveying system. This system blows the chips by means of a 450-hp. blower to any one of three outside storage areas or to either of two chip storage bins.

The outside storage areas are maintained and chips are reclaimed by means of a bulldozer. Three reclaiming pits equipped with conveyors and rotary pocket feeders deliver the chips to a second pneumatic conveying system equipped with a 450-hp. blower that will deliver the chips to either of two storage bins.

The wood preparation and chip handling departments are designed to handle, on a segregated basis, pine and two types of hardwood. The outside chip storage areas are designed for a capacity of 18,000 cords of chips. One chip storage bin is provided for pine and one for hardwood. Both bins are 40 ft. diam. and both are equipped with rotary turntable dischargers that are 17 ft. diam. and rotate at 6 r.p.m. The pine bin has a capacity of 60,000 cu. ft. and the hardwood bin has a capacity of 28,500 cu. ft.

The chips discharge from either of the storage bins to a $3^1/_2$ ft. wide inclined belt which runs in troughing idlers over a weightometer and discharges to a tripper conveyor that delivers the chips to any one of the four digesters. The capacity of this conveying system is 32,000 cu. ft. per hr. The turntable dischargers are automatically stopped when a preselected weight of chips has passed over the weightometer or when radioactive type of density measuring gages, on the digesters, indicate that the digester is filled to the desired level. The total weight of chips is integrated and the rate of flow is recorded. The digesters are equipped with capping valves rather than conventional heads and the tripper conveyor can be positioned over any desired digester by remote control.

Backhoe and flume

Chip storage

Digester Controls

All liquor, both black and white, is metered into the digester directly from storage by indicating and integrating meters that automatically stop the pumps and close valves when the preselected volume is pumped into the digester. Steaming and relieving of the digesters is done by completely automatic controls. Steaming is controlled by flow during the early stages and automatically transfers to digester pressure control during the latter stages of the steaming period. Relief flow is automatically controlled inversely proportional to steam flow. Charts record steam flow, relief flow, digester pressure, and temperature at two points in the digester. The digester relief is passed through an entrainment separator to a turpentine condenser and turpentine is recovered in a conventional system.

The four 6100 cu. ft. digesters are connected to blow line manifolds that allow any of the digesters to be blown into either of two blow tanks. One blow tank is for hardwood and the other is for pine. Blowing is by means of remotely operated motorized blow valves. The vapor lines from the two blow tanks pass the vapor to a common blow condenser which is mounted on top of the blow heat accumulator. The pine blow tank has a capacity of 24,000 cu. ft. and the hardwood blow tank has a capacity of 17,500 cu. ft. Both tanks are equipped with bottom entry, vertical, three-blade sweep type agitators. The load on these agitators automatically regulates the consistency in the blow tank.

Refining, Screening, and Washer System

The stock from the blow tanks is handled separately and in a somewhat different manner. The pine stock is pumped by means of a hydraulically controlled variable speed coupled pump through a breaker trap, with the pressure on the discharge side of the breaker trap regulating the pump speed. The stock passes from the breaker trap through two refiners in series and then to a hot stock screen. The accepted stock from the screen passes directly to a three drum, three-stage set of vacuum washers, $11^1/_2$ ft. diam. by 16 ft. in length. This phase is duplicated with a second set of refiners, screen, and washers, with a third screen serving as a spare to either line of washers. Both lines of washers discharge into a common screw-conveying system which conveys the washed stock to the pine high-density storage tank. This tank is a flat bottom tank of 120-ton capacity, equipped with mining nozzles and agitators. The rejects from the hot stock screens drop by gravity into a reject surge tank.

Digester and blow tank area

These rejects are pumped back to the pine blow tank for another pass through the refining system.

The hardwood system has a similar pumping system and breaker trap, but no refiners. The stock passes directly from the breaker trap to the hot stock screen. The accepted stock from the hot stock screen passes directly to a set of three-drum, three-stage, 8-ft. diam. by 12-ft. long vacuum washers. The washed stock is conveyed by a system of screw conveyors to the hardwood high density storage tank. This is a cone bottom tank with a blow tank type agitator and consistency control system with a capacity of 60 tons. The rejects from the hardwood screen flow to the common reject surge tank and are processed through the pine blow tank along with the rejects from the pine screens.

Hot water for all three sets of washers is pumped directly from the blow heat accumulator through a strainer to the washers. The water temperature is regulated by steam addition to accumulator or cold water addition to pump feeding the washers—whichever is required.

The drop legs from all three lines of washers deliver into a common set of three seal tanks. The weak black liquor leaving the system is filtered by means of a precoat filter before flowing by gravity to the weak liquor storage tanks.

All operations in the pulping department are remotely controlled from a central control room. This includes all operations from the chip storage bins to the high density storage tanks.

Evaporators

The weak liquor is processed through a sextuple effect evaporator to increase the per cent solids from 13.5 to 50% total solids. Each effect is equipped with a stainless steel mesh pad entrainment eliminator installed in larger than normal diameter domes.

Flow of liquor through the unit is with the feed split between the fifth and sixth effects, fifth effect discharge also going into the sixth effect. The discharge from the sixth effect passing to the fourth effect, then to soap skimmer and back to the third effect, from the third effect to the first effect, from the first effect through the second effect in two passes and to strong liquor storage. Each effect contains an internal liquor heater for elevating the liquor temperature as it passes from effect to effect. Capacity of this unit is 423,000 lb. per hr. of feed with an evaporation of 324,000 lb. per hr. and an economy of 5.41 lb. of evaporation per pound of steam.

Recovery Furnace

The chemical recovery furnace is rated at 1,250,000 lb. of black liquor solids per day, 183,000 lb. of steam per hour at 600 p.s.i. This unit is of standard design with a twin wheel side by side cascade evaporator, economizer, platen type superheater, decanting bottom, single-sided electric motor driven steam supplied soot blowers, turbine driven induced draft fan and smelt dissolving tank vent demister. The liquor going to the unit passes through a twin unit wet bottom precipitator with a design efficiency of 98%. Liquor flow to the 10 spray nozzles at 68 to 70% total solids is measured by a magnetic flowmeter and controlled by a hydraulically coupled variable speed pump with air flow being completely automatically controlled based on liquor flow.

Combination oil-gas auxiliary burners are equipped with gas pilot torches, and a complex system of safety controls designed to incorporate the latest developments in safety devices.

The density of the green liquor leaving the dissolving tank is automatically controlled by means of a radioactive type of density measuring gage that controls the weak wash dilution to the dissolving tank.

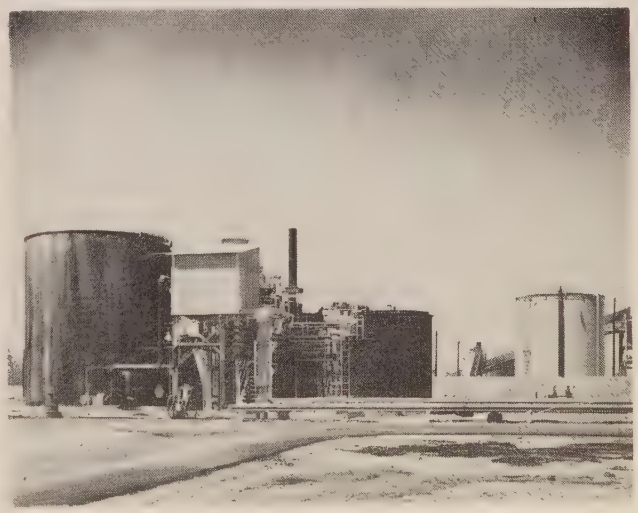
The controls for the furnace and the evaporator are mounted adjacent to each other so that one operator can be responsible for the operations of the furnace, evaporator, and precipitator.

Tall Oil Plant

The soap skimmed from the black liquor during the evaporating phase is delivered to a soap storage tank at the tall oil plant. From this storage tank the soap is processed through the tall oil cooker with the finished tall oil being pumped to tall oil storage for shipment by rail to purchasers. The spent acid, spent caustic, and separated black liquor are returned to the weak black liquor storage tanks.

Causticizing and Lime Recovery

The causticizing department contains a single compartment green liquor clarifier 35 ft. diam. by 24 ft. high, a dregs mixer 7 ft. diam. by 7 ft. high, and a dregs washer 22 ft. diam. by 24 ft. high for clarification of the green liquor and washing the soluble chemical from the solids removed from the green liquor. The clarified green liquor is stored in a tank 35 ft. diam by 28 ft. high. The clarified green liquor is metered from the storage into the slaker which is a conventional unit. From the clarified section of the slaker the liquor flows through three causticizers, 12 ft. diam. by 10 ft. high, in series and finally to a white liquor sump. This sump is maintained at a constant level by means of a hydraulically coupled variable speed pump with the pump speed being controlled by the sump level. Lime is metered into the slaker by means of variable speed screws which withdraw lime from a fresh lime tank or a reburned lime tank.



Tall oil plant

Capacity of each lime tank is 150 tons of lime. The lime feeders may be operated separately or together as desired.

The white liquor is pumped from the sump to a conventional four-compartment white liquor clarifier. This unit is equipped with a rake lifting device that automatically raises and lowers the rakes as dictated by the strain on the rakes. The clarified white liquor overflows into twin white liquor storage tanks that are 38 ft. diam. and 28 ft. high. The underflow density is measured by a radioactive type of density measuring gage and the rate of underflow is controlled to maintain any desired density by means of a hydraulically coupled variable speed pump, the speed being controlled by the density measuring gage.

The lime mud underflow from the white liquor clarifier is delivered to a four-compartment two-stage lime mud washer. The lime mud is washed by filtrate from the lime mud filter, water from the lime kiln stack gas scrubber and makeup water as required. The underflows from the first stage washing and the second stage washing are handled with density measuring gages and variable speed pumps in the same way as the underflow from the white liquor clarifier. The lime mud washer is also equipped with an automatic rake lifting device the same as the white liquor clarifier. The underflow from the final stage is pumped to the lime mud storage tank which is 20 ft. diam. by 20 ft. high and is agitated by a three blade, top entry, sweep-type agitator.

Lime Mud Filtering

Lime mud is pumped from the lime mud storage to the vat of the lime mud filter. The rate is regulated by the hydraulically coupled variable speed pump and the density is controlled by a radioactive type density measuring gage which regulates dilution water into the pump suction to give the desired density.

The lime mud filter is a "precoat" type vacuum drum filter operating at 20-in. Hg vacuum and a discharge of 75% solids. This unit is equipped with a sweep type vat agitator, a variable speed drum drive and the conventional water sprays for washing. The cake leaving the filer contains about 0.5% alkali.

Lime Kiln

The cake leaving the filter is conveyed into the lime kiln by a screw conveyor. The kiln is 9 ft. diam. and 250 ft. long, and is equipped with a chain section, an induced draft fan, a primary air fan, a four-speed electric drive, an auxiliary gasoline engine drive, a stack gas scrubber, and a combination gas-oil burner. Natural gas is the primary fuel with bunker C oil as standby fuel. The scrubber is an integral part of the stack with the induced draft fan running in the hot gases ahead of the scrubber. The lime leaving the kiln drops into a drag conveyor which discharges into a bucket elevator. The bucket elevator discharges through a pipe into the top of the reburned lime tank.

The weak wash tank used as storage of liquid for dissolving the smelt in the recovery furnace dissolving tank is 28 ft. diam. by 28 ft. high and receives its supply from the overflows of the lime mud washer and the dregs washer.

Combination Boiler

The combination boiler is a fuel fired unit used to generate the steam needed for the plant above the amount generated by the recovery furnace. This unit is a two-drum, baffleless boiler with a superheater and a flue gas heated air heater. The unit is designed to operate on bark, gas, or oil with provisions for future firing of pulverized coal if this becomes desirable. The boiler is capable of generating 300,000 lb. per hr. of steam at a pressure of 600 p.s.i. and a temperature of 750°F. The bark is burned on a traveling grate and oil or gas is burned in tangential burners mounted near the four corners of the combustion chamber. The bark is delivered to the unit through four openings by means of a vibrating feeder that is supplied with bark from the bark storage bin by a flat belt conveyor. The boiler is equipped with a sand removal system and a cinder reinjection system. Soot is blown by means of steam supplied electric motor driven retractable soot blowers.

Boiler Feedwater Treatment

The feedwater for the boilers is made up of clean condensate returned from the evaporator, recovery furnace air heater, and the paper machine plus makeup that is treated by means of a hot lime zeolite water softening system. Water is drawn directly from the Tennessee River and treated through use of a heat exchanger and then to the hot lime tank where the temperature is elevated to 225°F. The water leaving the hot lime tank passes through three parallel piped filters and then through zeolite softeners. The treated water flows to the treated water storage tank and is delivered to the boiler feedwater pump suctions through a deaerator and deaerated water storage. Feedwater is supplied to the boiler by means of two turbine driven pumps and one electric motor driven pump. The boilers are equipped with continuous blowdown systems and chemical feed pumps. Amine treatment is supplied for the steam system.

Paper Mill

Stock Preparation. Both primary and secondary washed stock is stored at high density in vertical cylindrical tanks with provisions for removal at controlled consistency. The capacity of the primary high density storage is 120 tons, that of the secondary is 60 tons.

From the high density storages the diluted pulp is pumped to leveling chests. These are of tile construction and equipped with propeller-type agitators. The capacity of the primary leveling chest is 10 tons and of the secondary 10 tons, at 4.5% consistency in each case.

Stock from both leveling chests is pumped through consistency regulators and adjusted to desired consistency, about 4%, before being delivered to the refiners. There are a total of nine disk-type pressure refiners. Two are driven by 700-hp. synchronous motors and are used as ticklers. The remaining seven are driven through reducers by 700-hp. turbines and are usable in various combinations to refine the stock to the primary and secondary machine chests.

Stock from the machine chests is pumped through the final consistency regulators, tickler refiners, and magnetic flowmeters on its way to the suctions of the respective fan pumps. In both the primary and secondary systems, screens are located in the lines to the machine headboxes. Rejects from these screens are returned to the saveall chest.

Dry broke is reduced by means of a pulper located under the last drier, calenders, and reel. This broke together with trim and broke from the couch pit is pumped to a vertical cylindrical tile broke tank located adjacent to the machine room. This tank is 35 ft. in height and 32 ft. diam., designed to contain 10 tons of stock at 3% consistency.

Broke from this tank is returned through a breaker trap to the saveall, an 11½ by 16-ft. vacuum filter using sweetener stock from the leveling chest and delivering thickened stock to a chest from which it is pumped back to the primary system. Any unused process water escapes to the sewer only after removal of suspended fiber by filtration on this machine.

Magnetic flowmeters are installed to measure both primary and secondary stock flow to the machine and also to permit controlled use of mixtures of either stock and broke.

Starch is received by bulk shipment and metered dry from a storage tank for continuous cooking. Facilities permit its use either for water box application or wet end addition. Provisions for controlled addition of sulfuric acid, alum, and wet-strength resins are also included.

Centralized control of stock preparation activities is

facilitated by mounting electric controls and instruments on a panel on the operating floor near the refiners and saveall and close to a pulp testing station.

Paper Machine. The fourdrinier machine has a 262-in. wire which is 152 ft. 11 in. long. It is equipped with both primary and secondary pressure headboxes. Drive and supporting equipment includes a 54-in. suction couch roll, 42-in. lump breaker, 38-in. wire drive roll, three 18-in. and four 28-in. diam. wire return rolls of which two are driven, 38-in. breast roll, and 24 table rolls. Wire and table rolls are fiber glass covered. The fourdrinier is provided with 36-in. dandy roll, right 15-in.-suction boxes, and multiple unit shake.

The press section includes a first suction press, a second suction press, and a smoothing press. The suction rolls are 44 in. diam., rubber covered. Top press rolls are 38 in. diam., rubber covered. The bottom smoothing press is microrock covered. Two press felts are used, with a conditioner on each.

There are four drier sections with breaker stack between the second and third sections. The four sections comprise 64 paper driers, two Feeney driers, and four felt driers. In addition there are four intercalender driers. All dryers are 60 in. diam. and designed for steam pressures up to 150 lb. The drier section is equipped with closed hood and conventional vapor removal system. The rope carrier is especially arranged to prevent broke fouling the system.

Two open sided calender stacks of the latest design provide for eight rolls each. Bottom rolls are 40 in. diam. Intermediate and top rolls are 18 in.

The reel, of heavy duty design, has a 48-in. diam. constant speed drum suitable for making reels up to 88 in. diam.

The winder is of heavy-duty two-drum design built for a maximum speed of 5000 f.p.m. Drums are 24 in. diam., shear cut slitters are used and both drums are motor driven.

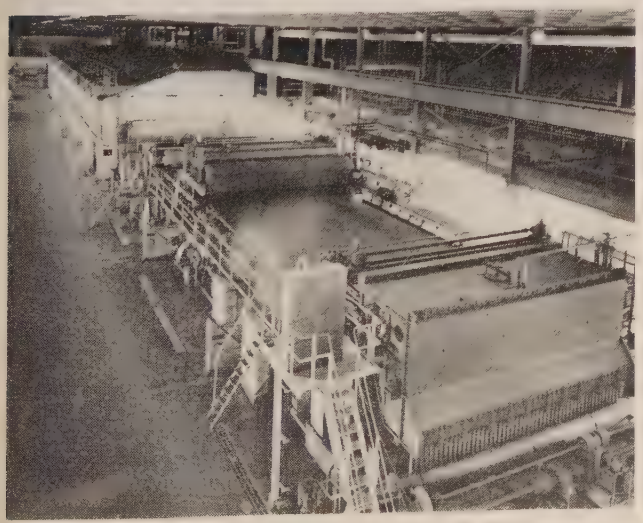
The winder is followed by a cross conveyor equipped with shaft puller, roll breaker, and hydraulic lowering device.

The machine is driven through an Extremultus belt drive by a 2300-hp. turbine permitting speeds of from 400 to 2000 f.p.m. Oil is supplied to calender and drier sections by a continuous oiling and filtering system.

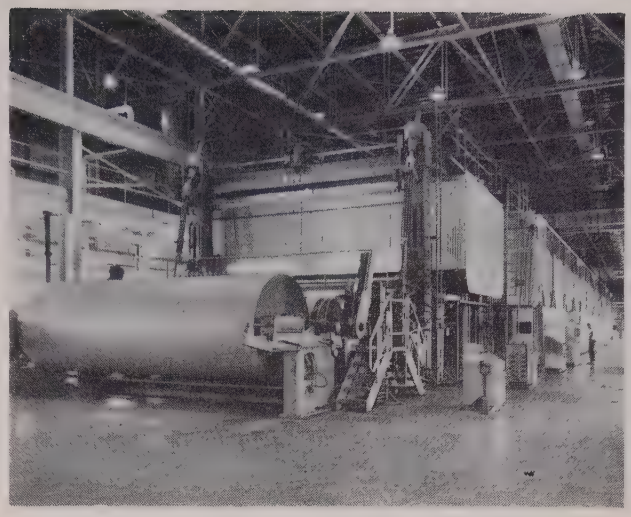
To attain maximum accuracy in weight control and uniformity, a scanning radioactive gage is used with pickup mounted at the reel. An automatic control maintains uniform moisture.

A recording linear footage counter is located at the scale following the winder.

Leaving the weighing station, rolls are conveyed to the warehouse level by means of a lowerator.



Paper machine wet-end



Machine, loading toward wet end

Warehouse and Shipping

A paper storage warehouse designed for retention of upwards of 7500 tons of rolls stored on end adjoins the machine building. The finishing area includes a 120-in. rewinder capable of winding 72-in. diam. rolls. A covered rail loading dock extends along one side of the warehouse which is also provided with truck loading facilities.

Mill Water System

The mill water is drawn from the lake above Pickwick Dam through an intake line 4 ft. diam. that extends out into the lake for a distance of 785 ft. The end of this intake line is arranged and anchored so that water is drawn from a point 6 ft. above the bottom of the lake and 19 ft. below normal water level.

The water flows by head differential through a shut-off valve and into a sump 25 ft. deep. It is then screened through a traveling screen to the suctions of three vertical type pumps driven by 450-hp., 1800 r.p.m. motors to deliver 5200 g.p.m. each to the mill at a mill pressure of 60 p.s.i. Prior to delivery to the mill, the water is automatically chlorinated at this pumping station. Each pump is equipped with an 8-in. pressure relief valve set to open and dump back into the sump at a pressure of 100 p.s.i. The supply line to the mill is 30 in. diam. and is equipped with vacuum relief valves as needed.

The water system at the mill has built-in systems to reuse water in a number of places. The contaminated condensate from the evaporator may be used for make-up water to the flume and to the causticizing department. The evaporator condenser cooling water may be used for make up to the blow heat accumulator tank.

A complete water treatment plant purifies all water used for drinking and sanitary purposes.

Steam System

Steam, as previously mentioned, is generated at 600 p.s.i. and delivered to unit drive turbines throughout the plant. Turbine exhaust at 160 p.s.i. plus pressure reducing and desuperheating stations supply steam at 150 p.s.i. for the paper machine, digesters, and other uses. One group of turbines exhausts at 75 p.s.i. and this steam plus pressure reducing (160 to 75 p.s.i.) and desuperheating stations supply 75 p.s.i. steam for evaporator and other low pressure uses.

Electric Power System

T.V.A. furnishes all electric power used at the plant. Power is brought to T.V.A.'s 15,000 kva. substation adjacent to the mill fence by 161,000 v. transmission lines, reduced

Night view of power group

first to 13,000 v.., and then to 2300 v. Mill distribution is at 2300 v. with transformers reducing to 440, 220, and 110 v. as needed.

Effluent System

The mill effluent is piped to the effluent pond in a closed pipe, passes through the effluent pond in a half pipe, then passes through the dam across the lower end of the pond and to the river in a closed pipe. The pipe at the outlet of the pond contains a gate and a recording conductivity meter is located in the pipe so that effluent conductivity is continuously recorded. This arrangement results in the ability to pond the effluent, in the event of contamination, until corrective action may be taken and sufficient diluting accomplished to bring the resultant total effluent within prescribed concentration limits. The outfall on the bottom of the river is equipped with numerous diffussion nozzles so as to diffuse the total effluent over a wide area of the river bottom. The gate and pond arrangement also allows the effluent to be discharged in proportion to the river flow whenever this is desirable. Sanitary sewage is treated in a sewage treatment plant prior to discharge through the effluent pond.

Maintenance Facilities

The mill is equipped with excellent maintenance facilities consisting of fully equipped machine shop, knife and slitter grinding equipment, roll grinder, electrical shop, instrument shop, welding and mechanic's shop, paint and oil storage building.

Chemical Handling

Salt cake and lime are unloaded by means of vacuum unloading and transfer systems with these chemicals being received in hopper bottom rail cars. Sulfuric acid, alum, bunker C fuel oil are received by rail tank cars. Tall oil and turpentine are shipped by rail tank cars.

Air System

Three 800 c.f.m. compressors supply the mill with the compressed air needed for operation. Air pressure is 100 p.s.i. Two of the compressors are turbine driven and the third is electric motor driven. One of the turbine driven units supplies mill air and one supplies instrument air. The electrically driven unit is for stand-by purposes. The instrument air is dried by a two-cell automatic switching and regenerating silica gel charged drier. A pressure-controlled automatic cross connection is provided to admit mill air ahead of the instrument air drier in the event that instrument air pressure drops below the control point.

Wood and Land Division

The job of supplying the mill with the 800 cords of pulpwood which are required each day to operate at its present rate of production is assigned to the Wood and Land Division of the company's operating organization. This division is staffed with 22 technical foresters and is divided into two departments, the Wood Procurement Department and the Land Management Department.

Wood Procurement

The Wood Procurement Department is charged with the responsibility of purchasing and transporting an adequate supply of pulpwood in a manner which will result in an even flow of good quality wood to the mill at all times and at reasonable costs. In order to do this job efficiently, there are, in addition to a superintendent in the central office, three area foresters—one each for Mississippi, Alabama, and Tennessee—and eight conservation foresters. The conservation foresters are scattered throughout the procurement area extending 150 to 200 miles from the mill into the states mentioned.

This department is also assigned the task of educating, working with and encouraging the small forest landowners in the use of the most profitable methods in the practice of forestry. This assistance is given only to those landowners within the main wood drawing area and is done with the plan that their lands will not only be a valuable asset to them, but will be a continuous source of pulpwood supply for this mill for years to come.

Wood located within a distance of about 75 miles of the mill is delivered by trucks. The balance which is loaded at more distant points is transported by the six railroads which form a network throughout the procurement area.

Land Management

The Land Department has the primary functions of administering and managing the 159,347 acres of company-owned land located in the tristate area surrounding the plant. Since the purpose of owning these lands is to guarantee at least a portion of the mill's supply of pulpwood, the most modern methods of forestry are practiced so as to produce the maximum forest values consistent with good business principles and the company's needs. In order to carry on this work, this department has, in addition to a superintendent in the central office, seven technical foresters heading up the work in the six administrative districts into which the property is divided.

Since 1953, this department has planted over 33 million pine seedlings on poorly stocked acres of forest lands. It has also removed cull hardwoods where competing with pine from 65,000 acres of unproductive lands. It has surveyed and marked many miles of property lines, maintained a system of fire trails and roads, and suppressed many forest fires. In addition to these jobs, in cooperation with the Tennessee Valley Authority, it has carried on an active program of research and has established a seed orchard leading to the production of genetically superior forest trees.

While it is expected that these efforts will lead to a vast increase in pulpwood production on these lands in time, it is anticipated that company-owned forests will never produce more than 50% of its pulpwood needs. The remainder will be acquired from private lands.

Major Suppliers to Tennessee River Pulp & Paper Co.

Allis-Chalmers—Process pumps
American-Blower—Fluid drives and boiler fans
American Tool—Machine shop equipment
Bailey Meter Co.—Recovery furnace and combination boiler controls
Bauer Brothers—Hot stock and paper mill refiners
Beloit—Complete paper machine and winder
Black-Clawson—Breaker traps, selectifier screens, and rewinder
Buffalo Forge—Machine shop equipment

Carrier Conveyor—Bark distributing equipment
Chain Belt—Chip storage bins, tripper conveyor and chains, and water screen
Chicago Bridge and Iron—Multiple effect evaporator
Chicago Pump—Sanitary sewage treatment
Cochrane—Boiler feedwater treatment plant
Colchester Lathe Co.—Machine shop equipment
Combustion Engineering—Recovery furnace and combination boiler
Copes-Vulcan—Steam desuperheating equipment
Corn Products—Bulk starch handling equipment
Deaderick Co., R. D.—Machine shop equipment
Detecto Corp.—Paper scales
DeWalt—Machine shop equipment
DeZurik—Consistency regulators and process valves
Diamond Power Co.—Scott blowers
Dorr-Oliver—Causticizing system and lime mud filter
Dunlop—Conveyor belting
Elliott Co.—Unit drive turbines, power and recovery
Farrell-Birmingham—Roll grinder
Fibre Making Process—Barking drums
Fisher—Control valves
Fisher Porter—Chlorinator
Foxboro—General mill instrumentation
Fuller Co.—Salt cake and lime handling system
General Electric—Motors, motor controls, transformers, and turbines
Goulds—Process pumps
Graver Water Conditioning Co.—Deaerator
Gruendler—Bark hog
Gulf Oil Corp.—Lubrication consultants
Hammond Iron Works—General tankage
Hanchett Manufacturing Co.—Slitter knife and chipper knife grinders
Harbison-Walker—Refractories
Hercules Powder Co.—Size system
Hobart—Welding machines
Hyster—Fork and roll grab trucks
Improved Machinery Co.—Hot stock screens, brown stock washers, saveall, foam breaker, and Waco filter
Industrial Corp.—Air drier
Industrial Nucleonics—Basis weight control
Ingersoll-Rand—Air compressors and boiler feedwater pumps
International Harvester—Bulldozer
Jamesbury—Liquor valves
Jones, E. D.—Pulpmaster
Kearney & Trecker Co.—Machine shop equipment
Koehring—Wood handling truck crane
Koppers Co.—Precipitators
Layne Bowler—Mill supply water pumps
Link Belt—Paper machine lowerator, flume screens, and screw conveyors
Lorain—Wood rake
Merrick Scale Manufacturing Co.—Chip weightometer
Miller-Hofft—Bark bin
Murray, D. J.—Chipper
NALCO—Water treatment consultant
Nash Engineering Co.—Vacuum pumps
Northern Engineering—Bridge cranes
Ohio Electric Co.—Electromagnets
Ohmart Corp.—Density meters
O. I. C.—Process valves
Oster Manufacturing Co.—Machine Shop equipment
Otis Elevator Co.—Freight elevator
P. & H Construction Equipment—Wood handling crane crawler
Peabody Engineering Corp.—Gas scrubber and fuel oil set
Peerless Pump Co.—Flume pumps and fire pumps
Philadelphia Gear Corp.—Blow tank agitator reducers
Pratt, Henry—Starch cookers
Radar Pneumatics—Chip blowing system
Reliance Electric Co.—Paper machine helper drive
Roper—Soap pumps
Rosenblad Corp.—Turpentine condenser
Ross, J. O.—Machine air system and mill air conditioning
Rovang—Capping valves and stainless steel piping
Rudel Machine Co.—Machine shop equipment
Smidth Company, F. L.—Lime kiln
Sparkling Meter Co.—Digester liquor meters
Stamm—Drier controls
Stupp Brothers—Structural steel
Tannewitz Works—Machine ship equipment
Toledo—Truck scales
Westinghouse—Process motors, motor control, and transformers
Worthington—Evaporator pumps
Wyatt Metal & Boiler Works—Digesters
Yarnall-Waring—Blow valves

WEYERHAEUSER CO.

Weyerhaeuser Co. formally opened a new shipping container plant in Olympia, Wash., June 23, 1961. The plant, which eventually will employ about 100 persons, is producing all types of corrugated containers from paperboard supplied by Weyerhaueser mills at Longview, Wash., and Springfield, Ore.

The 95,000-sq.-ft. facility is the 26th shipping container plant operated by Weyerhaeuser and the second located in the Pacific Northwest. The company also operates a plant near Yakima.

Educational Institutions

INSTITUTE OF PAPER CHEMISTRY

Commencement

Ten Ph.D. degrees were awarded to graduates of The Institute of Paper Chemistry in Appleton, Wis., June 11, at commencement exercises of Lawrence College.

This brings to a total of 187 the number of Ph.D. degrees provided by the Institute since its founding in 1929.

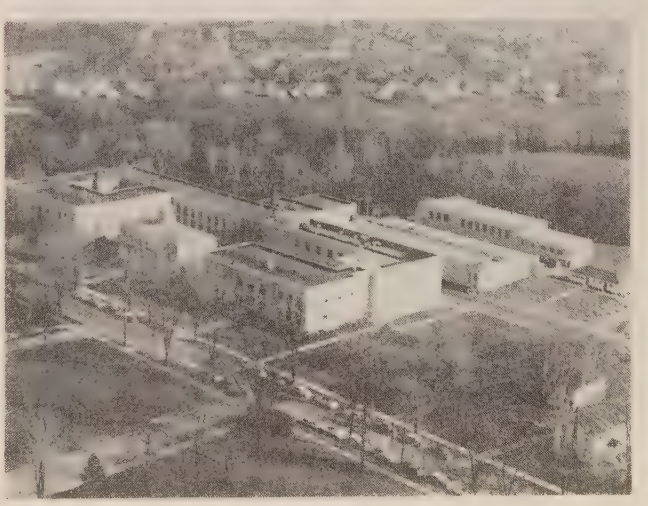
The Institute of Paper Chemistry—1931

Statistics indicate The Institute of Paper Chemistry ranks in the upper quarter of the hundred and four universities granting Ph.D.'s in chemistry and chemical engineering.

Twenty-one Master of Science degrees were awarded this year. All but three will continue study at the Institute toward their Ph.D. degree. The three terminating their study are entering directly into the pulp and paper industry.

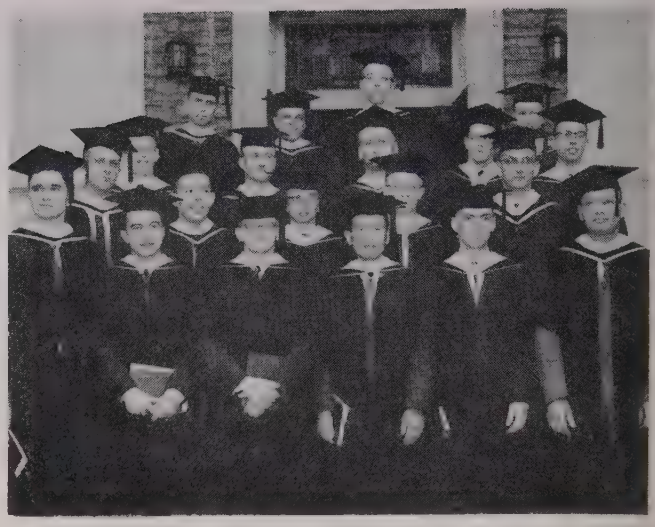
The last M.S. degree awarded at this year's commencement was the 300th given by The Institute of Paper Chemistry, and went to Lyman K. Woodbury, Jr., of Portland, Me.

Winner of the Westbrook Steele gold medal award for the outstanding research thesis of the year was Ronald Estridge



The Institute of Paper Chemistry—1961

Awarded Ph.D. degrees at the Institute



Awarded Master of Science degrees

of High Point, N. C. The winner of the annual award is selected by the Institute faculty.

Another award made annually is the Paper and Twine Association Award of $150 to the outstanding first year student at the Institute. The winner of this award will be announced by the Association.

Institute Alumni

With the entrance of the ten Ph.D. degree recipients and the three M.S. recipients who are terminating their study, The Institute of Paper Chemistry's alumni body now numbers 440, including 57 who were special students.

Over 80% of the Institute's alumni are in pulp and paper or allied industry, according to Dr. Edwin R. Laughlin, secretary of the Institute's alumni association.

Listed among the Institute's alumni in the pulp and paper industry are the presidents of five companies, the board chairman of one company, 21 vice-presidents, 25 research directors, and 30 technical directors.

Alumni are represented in 42 states and ten foreign countries, including Switzerland, Mexico, Scotland, Peru, England, Canada, India, Burma, and Formosa.

Twenty Institute alumni have gone into education as members of college or university staffs, two are heads of departments at universities.

J. Edward Todd, retiring dean of admissions of The Institute of Paper Chemistry, receives the academic hood of the honorary Master of Arts Degree ad eundem *awarded him by Lawrence College, Appleton, Wis.*

Anticipated Student Body

The Institute of Paper Chemistry anticipates a student body of approximately 75 in its graduate school for the 1961–62 academic year. The student body of 75 last year broke previous enrollment records. The second year class which received Master of Science degrees at this year's commencement exercises set a record of being the first to remain intact during the first two years of Institute study.

Application for entrance into the Institute graduate school is open to anyone who has a Bachelor's Degree, and whose undergraduate curricula contains necessary prerequisites for the Institute's graduate program. Full time scholarships are awarded to all students who are accepted by the graduate school.

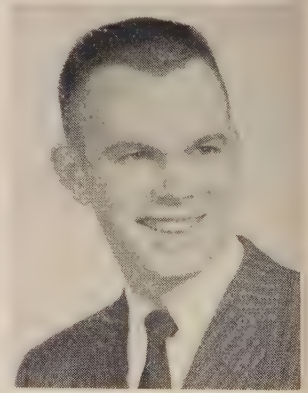
Dean of Admissions Retires

Dr. J. Edward Todd, Dean of Admissions at The Institute of Paper Chemistry since 1942, has retired from the Institute staff as of the close of the academic year. He was awarded the Master of Arts degree *ad eundem* by Lawrence College, (Appleton, Wis.) at its commencement exercises, June 11.

According to an announcement by John G. Strange, president of The Institute of Paper Chemistry. Dr. Todd will continue to serve in a consultative capacity.

Westbrook Steele Gold Medal

The Annual Westbrook Steele Gold Medal award, one of two awards given annually to students of the graduate school at The Institute of Paper Chemistry, was given this year to **Ronald Estridge,** formerly of High Point, N. C., and presently on six months' active duty with the U. S. Army at Valley Station, Ky.



Ronald Estridge, recipient of the Westbrook Steele Gold Medal Award

Established in 1941, the Westbrook Steele gold medal is awarded annually to the candidate for the degree of Doctor of Philosophy who submits the outstanding thesis for that year. Nominations for the Steele medal are made by a faculty committee and approved by the entire faculty of The Institute of Paper Chemistry.

Sixth Industry Seminar

Twenty-five men from 25 of the nation's pulp and paper companies arrived in Appleton, Wis., Sunday, June 11, to begin The Institute of Paper Chemistry's Sixth Industry Seminar.

After a reception at the Conway Hotel Sunday night, introductory sessions of the three week seminar got under way Monday morning with Neil McLeod, Institute economist and Seminar director, and Geo. D. Jernegan, Institute director of continuing education.

Subjects ranging from air pollution abatement, through packaging, process control, graphic arts, pulping, converting, and paper evaluation will be presented at the Seminar, utilizing 21 of the Institute staff members in formal presentations, and others in a less formal capacity.

Pioneering Research Program

Support of almost a hundred and a quarter thousand dollars a year for the Pioneering Research Program of The Institute of Paper Chemistry was announced at the Institute's Executives' Conference in Appleton, Wis., May 25, 1961.

Twenty-four companies and foundations have subscribed the support for an initial period of five years according to the report made by Kyle Ward, Jr., chief of the Institute's cellulose group.

Four research projects have already been placed by the Program's Committee, and several more are in the process of consideration from the proposals so far received.

Miami University

As Miami University at Oxford, Ohio, graduated the first class of its industry-sponsored paper technology program, first of its kind in Ohio, an honorary Doctor of Laws degree was conferred upon Howard E. Whitaker, Mead Corp. chairman who has headed both the industry advisory committee for the program and the foundation through which

Miami University: John Swafford, James R. Weber, and Howard E. Whitaker

industry now helps support it. Shown on that occasion: John Swafford of Oxford and James R. Weber, Brookville, Ohio, who among the program's first seven graduates have been accepted by The Institute for Paper Chemistry at Appleton, and Mr. Whitaker, who also is president of the American Paper and Pulp Association.

North Carolina State College

This year's graduates in pulp and paper technology from North Carolina State College's School of Forestry have accepted employment in the pulp and paper industry with companies located in states from Texas to New York, from Florida to Arkansas. Of the 20 who graduated this year, 10 have accepted industrial employment. Three of the 1961 graduates will attend summer school; four have accepted fellowships for postgraduate study; one will enter military service; and two have not yet committed themselves.

Industry Suppliers

Albany Felt Co.

Plant Improvement Program

A million dollar plant improvement program which will enable Albany Felt Co. to expand production and provide new and larger styles of customized paper machine felts has been announced. A total of $680,000 will be spent to enlarge the St. Stephen, S. C., plant to provide it with equipment for manufacture of needled felts, and for new and larger looms.

At Albany, N. Y., a $350,000 program is under way, including acquisition of new needling equipment which will allow the needling division to service a wider range of paper machines.

In addition, two large looms, one measuring 550 in. and the other 670 in., will soon be delivered to Albany.

At South Carolina, construction of a 33,000-sq. ft. one-story addition of 12-in. jumbo brick is already under way. The space will provide for future expansion in weaving, yarn-making and needling.

Agency

The Albany Felt Co., announces the appointment of Paper Mill Suppliers, Inc., Kalamazoo, Mich., as the exclusive agency for the distribution of Dri-Tuft and Dri-Weave drier felts manufactured by Albany Felt Co.

Paper Mill Suppliers, Inc., is headed by **Frank Clawson,** formerly regional manager for Brandon Sales, Inc. The firm's address is Box 831, Kalamazoo, Mich.

Air Reduction Chemical Carbide Co.

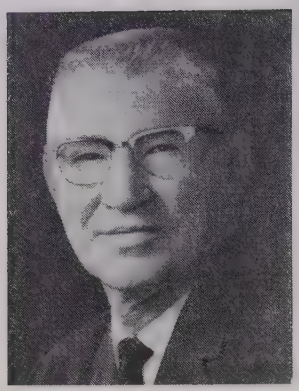
A new, comprehensive list of products manufactured by Air Reduction Chemical & Carbide Co., a division of Air Reduction Co., Inc., has just been issued. The eight-page bulletin gives information on a large group of products, ranging from calcium carbide and pipeline acetylene to organic compounds and special-purpose resins. Copies of the bulletin, entitled "AIRCO—Organic Chemicals and Colton Polymers," are available from Air Reduction Chemical & Carbide Co., 150 E. 42nd St., New York 17, N. Y.

Also available are two abbreviated versions of the Airco bulletin, covering the product lines of two of the company's chemical marketing departments. A six-page bulletin entitled "Colton Polymers" lists the physical properties and applications of the products marketed by the Colton polymers department. Among the products included in the bulletin are Airco "Vinol" polyvinyl alcohols, "Flexbond" copolymers, "Vinac" polyvinyl acetates, "Flexac" polyvinyl acetates, and "Aircoflex" dibutyl phthalate.

"Airco Organic Chemicals" is a four-page bulletin covering Airco vinyl monomers, acetylenic alcohols and glycols, alkyl acetylenes, and "Surfynol" surface active agents. These products are marketed by the organic chemicals department of Air Reduction Chemical & Carbide Co.

Allis-Chalmers Mfg. Co.

A new device, providing greater flexibility in the operation and maintenance of wire cloth and plate decks on vibrating screens, has been developed by Allis-Chalmers. The new device makes it possible to change screen decks in only a fraction of the time formerly required and permits tensioning of cloth while the screen is in operation. It is available on all new Allis-Chalmers vibrating screens, as well as replacements for those already in operation.



Douglas E. Turnbull, The Bauer Bros. Co.

M. J. Peters, John W. Bolton & Sons, Inc.

BAUER BROS. CO.

A completely revised bulletin (P-24-A) on No. 606-6 in. and No. 607-6 in. Bauer Centri · Cleaners is now available from the Bauer Bros. Co., 1715 Sheridan Ave., Springfield, Ohio. The new bulletin outlines typical applications for both cleaners and contains information on ceramic cones and bell type overflow nozzles for both units, as well as pertinent operating and installation data.

Staff

Douglas E. Turnbull has been named as a new sales representative for the Bauer Bros. Co., Springfield, Ohio, it was announced by E. L. Rastatter, vice-president of Sales. He will cover the Ohio, Indiana, and Michigan area.

BIRD MACHINE CO.

New Bird Cycleans in the 7 and 12-in. diam. are equipped with a newly designed baffle head that prevents ingress of air. Instead, the air goes out with the rejects and this applies also to some of the entrained air in the stock. The new baffle head Cycleans are complete and self-contained. Vacuum rejects systems and water elutriation systems are not required. They are also equipped with sintered ceramic cones. The 7-in. diam. Cyclean has an inlet capacity of 120 g.p.m. and the 12-in. diam. Cyclean provides an inlet capacity of either 500 or 850 g.p.m.

JOHN W. BOLTON & SONS, INC.

Marcus Jackson Peters has been appointed sales representative in the territory which includes Georgia, Alabama, and Florida for John W. Bolton & Sons, Inc., Lawrence, Mass., a leading manufacturer of machine knives for industry.

14th Bolton Award

Edward L. Schuette, a paper tester for the Brown Co. of Berlin, N. H., became the winner of the $1000 first prize in the 14th annual Bolton Award essay contest it was announced by F. Richard Convey, general sales manager of Bolton-Emerson, at the 42nd Annual Convention of the Paper Industry Management Association at Jacksonville, Fla.

Winner of the second prize of $750 is Clifton J. Walker, map draftsman for the E. B. Eddy Co., Hull, Que., who won third prize in last year's 13th Bolton Award.

Andrew J. Rego, purchasing understudy at Kimberly-Clark Corp., Neenah, Wis., receives $500 as winner of the third prize in this year's contest.

$200 prize winners announced by Mr. Convey include:

Robert E. Lee, Jr., quality control supervisor, Rochester Paper Co., Rochester, Mich., also a prize winner last year.

H. S. James, Jr., director of public activities, Union Bag-Camp Paper Corp., Franklin, Va.

Brad Block, research analyst, Kimberly-Clark Corp., Neehah, Wis.

Mrs. Joann Graham, secretary, Industrial Relations Dept., Packaging Corp. of America, Hutchinson, Kan., another prize winner last year.

Harry M. Bowser, manager—sales services, Dairypak Butler, Inc., Olmsted Falls, Ohio.

Thomas H. Schumann, director of industrial relations, The Mead Corp., Leominster, Mass.

Mrs. Margie Louise Cunningham, secretary, Packaging Corporation of America, Hutchinson, Kan.

In announcing the ten prize-winning contestants, Mr. Convey pointed out that joint sponsorship by PIMA and John W. Bolton & Sons, Inc., of this yearly essay competition is serving "to promote better understanding of topics of universal interest throughout the pulp and paper industry and is stimulating interest from all industries.

In the fall, bound volumes containing the 10 winning essays and a composite paper summarizing the thoughts expressed among all contestants will be mailed out to members of the pulp and paper industry as a public service.

Others desiring copies of the 14th Bolton Award book may address requests to John W. Bolton & Sons, Inc., Lawrence, Mass., or to the Paper Industry Management Association, 10 N. Clark St., Chicago 2, Ill.

CAMERON MACHINE CO.

Cameron Machine Co., Dover, N. J., has added a 102-in. trim width, high-speed paper machine winder to its Testing and Development Section. This new winder, to be used for both experimental and testing purposes, can be equipped with either score-cut or shear-cut slitting elements. It has a 60 in. diam. rewind capacity and can run at speeds up to 6000 f.p.m.

A shaftless unwind stand equipped with continuous duty brakes is used in back of the winder. The unwind brake system provides a torque range from 56,000 in.-lb. down to 100 in.-lb. Automatic web tension control is supplied either by using the Model 950 dancer roll tensioning device or the pneumatic-hydraulic Web-Trol sensing device.

The winder is equipped with a differential drum speed control system, making it possible to control the density of the rewinding rolls. The drum speed control system, an integral part of the main drive isolated gear box, has been developed to provide a means of winding larger diameter rolls of coated papers with less danger of web breaks during subsequent printing processes.

With the addition of the new paper mill winder Cameron's Testing and Development Section is now equipped with five winders. All of the principles of slitting and winding used within the industries served by Cameron can be seen in this one location. The facilities of the Testing and Development Section have been made available to companies interested in test running new materials.

CHROMIUM CORP. OF AMERICA

Executive changes have been announced by Chromium Corporation of America, one of the country's largest custom plating organizations, operating plants in Waterbury, Conn.; Chicago and Cleveland. **William J. Zubrisky,** formerly executive vice-president, has been elected president and chief executive officer. He succeeds **Donald H. Bissell,** who has been named chairman of the board. **Joseph J. Cassidy,** formerly assistant treasurer, has been elected controller.

CIBA CO.

Valdemar Jacobsen, Ciba Co., Inc., sales representative, has been transferred from the Philadelphia district to the New England district.

Clinton Corn Processing Co.

Appointment of **Everett E. Hanke** as district sales manager for the New England states has been announced by A. C. Junge, vice-president—sales, Clinton Corn Processing Co., Clinton, Iowa. He will headquarter at Clinton's New England sales office in Somerville, Mass.

Fischer & Porter Co.

Application Bulletin 90-26-13, published by Fischer & Porter Co., 917 Jacksonville Rd., Warminster, Pa., discusses the continuous preparation of soda bleach by the use of a Fischer & Porter instrumentation system. The bulletin lists the components of the F&P system, outlines its operation, and cites some of the advantages, such as elimination of storage tanks, and increased uniformity of the bleach solution, that makes continuous preparation of bleach a valuable addition to the overall process.

Electrode Chamber

Application Bulletin 90-26-07, published by Fischer & Porter Company, Warminster, Pa., outlines the construction of a "build-it-yourself" pH electrode chamber designed to minimize the maintenance problems common to many conventional immersion- and flow-type electrode housings. The single-page bulletin provides a detailed drawings, with dimensions and specifications, for cutting out the 316 stainless steel pieces that comprise the chamber, and another drawing that illustrates assembly of these pieces.

Copies of Bulletin 90-26-07, "Electrode Chamber for Measuring White Water pH," are available from Fischer & Porter Co., 915 Jacksonville Rd., Warminster, Pa.

Foxboro Co.

A $700,000 assembly plant in East Bridgewater, Mass., was opened June 5 by the Foxboro Co., Foxboro, Mass., manufacturers of industrial instruments for measurement and control. Employing a staff of 150, the new 40,000 sq. ft.

$700,000 electronic assembly plant in East Bridgewater, Mass., opened by the Foxboro Co.

plant will allow Foxboro to expand the manufacture and assembly of electronic consotrol instruments which are being widely specified for process control system.

The new plant brings the Foxboro Co. total to six factories and branch factories within the United States, not including repair shops and 61 branch offices. Internationally, besides four manufacturing plants in England, Holland, Canada and an associated plant in Japan, there are 45 engineering firms representing Foxboro throughout the world.

Fuller Co.

Machinery for Process Industries

Rotary kilns, mills, crushers, feeders and other equipment for the mining and processing industries are described and illustrated in a new four-page two-color bulletin (TGB-2A) now offered by Traylor Engineering and Manufacturing, Division of Fuller Co., Allentown, Pa.

Self-discharging Carrier

A new self-discharging carrier for dry bulk materials called the Airslide pump is described in a new two-page two-color bulletin (FHP–1) now available from Fuller Co., Catasauqua, Pa. Included in the bulletin is a description of the flow of material through the combination tank-pump, by means of the fluidizing action of Airslide conveyors. Discharge control, equalization of air pressure, and minimisation of abrasive action are also discussed.

General Electric Co.

Appointment of six men to key posts in General Electric's recently formed Advance Planning and Projects Operation is a further development in the realignment of the company's industrial marketing organization in Schenectady.

The announcement was made by L. F. Lewis, manager of the operation which has been given broad responsibility for innovation and technical market development. In their new positions, the men will apply analytical techniques and combine old and new technologies to solve problems of G.E.'s industrial customers.

A new computer facility, comprising an analog computer coupled to a digital computer, will enable G.E. engineers to simulate complex industrial processes on one computer and try out various process control strategies on the other.

The computer facility will be administered by **R. A. Phillips,** newly appointed manager of analytical engineering. Besides Phillips, the following men were appointed and their functional responsibilities outlined:

F. S. Rothe, manager of process automation studies. Typical studies already under way in Mr. Rothe's organization include the chemical and petroleum, gas pipeline, paper, cement and steel industries.

W. C. Bloomquist, formerly manager of application engineering in the company's Philadelphia office, has been appointed manager—industrial power systems. Mr. Bloomquist will have combined engineering and commercial responsibility for this sector of the company's business.

C. M. Rhoades, manager—power utilization systems, will be responsible for finding new uses for many General Electric products. Applications of electric arc equipment, ranging from the forming of metal parts to the development of hypersonic gas velocities, illustrate activities from which new businesses could grow, Lewis said.

Fuel cells and other unconventional power supplies with potential for industrial application will be included in studies to be conducted by **L. W. Morton,** appointed consulting application engineer—power conversion technologies.

A sixth component, planning and development, will be headed by **J. F. Cronin,** Mr. Cronin, supported by a staff of application and sales engineers, will be responsible for developing new technical marketing approaches and evaluating project opportunities.

Advance planning and projects is a component in the Systems Sales and Engineering Operation, headed by **George W. Knapp.**

Glidden Co.

Two changes in the sales organization of the Glidden Co.'s Chemicals Division have been announced by George M. Halsey, vice-president in charge of the division.

Ralph B. Quelos has been named general sales manager—Pigments and Colors, and will be responsible for developing sales of titanium dioxide, lithopone, color ingredients, and copper pigments. He will be headquartered at Glidden's Adrian Joyce Works at Baltimore.

James C. Rankin will be general sales manager—Metals and Organic Chemicals, and will direct all sales activities in connection with the division's powdered metals, tall oil and fatty acids and terpene chemicals. He will be headquartered at Glidden's home offices in Cleveland.

HERCULES POWDER CO.

Two new sales managerial appointments in the Cellulose and Protein Products Department of Hercules Powder Company have been announced. **Richard S. Clark** has been named the department's district manager in San Francisco and **Joseph G. Jarrell** has been named district manager in the department's New York office.

Also announced are appointments of five sales executives in the Pine and Paper Chemicals Department. The appointments, effective immediately, are: **W. D. Thompson** becomes sales manager, chemical specialties—paper; **David S. Hollingsworth** is the assistant sales manager, chemical specialties—paper; **Robert J. Leahy** is named sales manager for rosin size; **Spencer H. Watkins** is assistant sales manager for rosin size; and **J. Houston McClane** becomes manager of national accounts—paper.

J. M. HUBER CORP.

Another advance in a long-range expansion and development program will be marked by J. M. Huber Corp.'s Chemicals Division, with the completion of a new research laboratory and administration building at Havre de Grace, Md.,

Artist's rendering of the new research laboratory for the Chemicals Div. of J. M. Huber Corp., Havre de Grace, Md.

in September, 1961. The new structures will augment plant facilities devoted to the manufacture of chemicals and synthetic pigments for the paint, paper, pesticide, ink, and rubber industries. The new building will augment present Huber research facilities in Borger, Tex., and Huber, Ga.

HUYCK CORP.

Formex Co.

Robert C. Farley, formerly with Ames American Co., has joined Formex Co., Division of Huyck Corp., as sales engineer in New England.

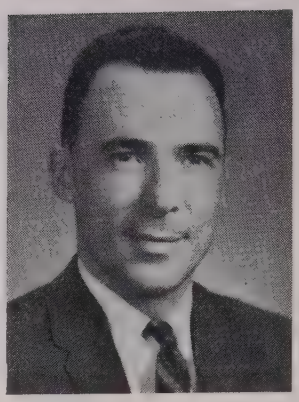
Formex Co. developed and now manufacturers Formex forming fabrics, the new synthetic fiber replacement for the traditional bronze fourdrinier wire.

I-T-E CIRCUIT BREAKER CO.

Richard L. Masterson has been named manager—Commercial Apparatus Group for the New Haven district office of I-T-E Circuit Breaker Co. Working from office at 2315 Whitney Ave., Hamden, Conn., he will handle sales in the state of Connecticut of the company's lighter commercial equipment for the control and distribution of electric power in commercial, residential and industrial applications.

KOHLER COATING MACHINERY CORP.

The Kohler Coating Machinery Corp., Greentown, Ohio,



Richard L. Masterson, I-T-E Circuit Breaker Co.

Henry Moser, Samuel M. Langston Co.

announces that it is now supplying the paper industry with a new electronic flaw detector and alarm system for papermaking machines, known as Inspectalarm. It provides immediate warning at the beginning of trouble on a paper machine by recording or marking the position of flaws. Inspectalarm will detect holes, cuts, dirt, discolorations, tears, wrinkles, cut-outs, oil spots and coating skips.

Once the flaw is detected, Inspectalarm can signal the flaw occurrence; distinguish between serious and minor flaws; sound an alarm; mark the paper edge so the position of each flaw in a reel is marked by a ring on the end of the reel; make a record of the number, distribution, and severity of flaws in a reel for evaluation by the papermaker; play back the record of flaws as a reel is unwound to warn, slow down, or stop the process in advance of reaching the flaw.

SAMUEL M. LANGSTON CO.

Samuel M. Langston Co. has promoted **Henry Moser** to vice-president—engineering, president Bryant W. Langston announced.

MIDLAND-ROSS CORP.

J. O. Ross Engineering

As part of an overall program for increased production, Di-Noc Chemical Arts, Inc., recently installed high velocity driers on a three-station Cottrell printing press at their Cleveland, Ohio, plant. The press originally had been equipped with a standard drier that could not properly handle the increase in production required. The new high velocity driers engineered and installed by J. O. Ross Engineering, a Division of Midland-Ross Corp., increases printing speeds by increasing air impingement velocities and reducing the off-setting.

Waldron-Hartig Div.

A new unique slide-chart has been developed by Waldron-Hartig. This calculator is being offered as a service to the web coating industries to provide immediate answers to coating problems, such as: (1) how many reams are produced per hour, (2) the total dry coat weight applied per hour, (3) the total wet coat weight applied per hour for any per cent solids, (4) the pounds per hour solvent or water which has to be evaporated, and (5) there is a ready conversion to approximate coating requirements in gallons per hour.

A copy of Waldron's "Coating Weight Calculator" can be obtained by writing to: Waldron-Hartig Div., Midland-Ross Corp., Box 791, New Brunswick, N. J.

MINNEAPOLIS-HONEYWELL REGULATOR CO.

A new specification describes the integral Honeywell-Beckman system for pH measurement. The new model 75 Beckman pH Amplifier is mounted in any of a variety of Honeywell ElectroniK 15 instruments, for greater ease of

measurement and economy of installation. It is no longer necessary to install a separate amplifier. The electrode leads are now just run directly to the recorder. The new model 75 amplifier uses the same standard Beckman glass and reference electrode and the same Thermo-Compensator used with the externally mounted model W pH amplifier, the standard for the industry. Complete specifications and ordering information are included in the sheet. For more information, write for S914–1.

Morden Machines Co.

Appointment of **Allen E. Carl** as West Coast sales and service engineer for Morden Machines Co., is announced by J. L. Sigler, director of sales and service of the Portland, Ore., manufacturer of stock preparation equipment for the pulp and paper industry. Mr. Carl replaces **James McAndie** who will now supervise sales and service in the Northeast and New England division.

Allen E. Carl, Morden Machines Co.

Mount Vernon Mills, Inc.

James E. Hooper, president of Wm. E. Hooper & Sons Co., and Tomas M. Bancroft, president of Mount Vernon Mills, Inc., recently announced the establishment of the Wm. E. Hooper Sales Co. as a division of the Mount Vernon Hills, Inc., and the purchase of Wm. E. Hooper papermakers drier felt operations by Mount Vernon Mills, Inc., effective July 1, 1961.

The Mount Vernon Dryer Felt Co., a div. of Mount Vernon Mills, Inc., will assume responsibility for the manufacture and sale of the Hooper drier felt operations and will add to its personnel a number of the present Hooper employees. Manufacture of the Hooper drier felts will continue uninterrupted in Baltimore.

Nopco Chemical Co.

A comprehensive line of wetting agents for diversified industrial uses is described in a new booklet (ISP-45) published by Nopco Chemical Co., Newark, N. J. The brochure suggests dozens of applications for wetting agents in the field of textiles, paper, metal processing, leather, protective coatings, and a variety of specialized uses. The publication also contains accurate Draves wetting times of the various Nopco wetting agents listed, with additional data on chemical and physical properties and general recommendations for use.

Pfaudler-Permutit, Inc.

Precipitator

The Permutit Co., 53 W. 43rd St., New York 36, N. Y., a division of Pfaudler Permutit, Inc., has released design and operating details of its new water-jet powered precipitator, a simplified and economical solids-contact type water clarifier that has already demonstrated high efficiency in field tests carried out over the past eight months.

Designated the type M Precipitator by Permutit, the new clarifier is described as a sludge blanket type, in which the jet effect of water ejected from the tips of the agitator is the sole driving power required for the agitator unit. This design eliminates both the electric motors commonly needed in this type clarifier and the catwalks and bracing usually required for support and access to the motor. The agitator of the type M precipitator rotates on a stub spindle and requires no overhead support.

In operation, raw water and chemicals are premixed and introduced to the Precipitator through an inlet at the center of the tank beneath the agitator hub. A conical deflector, on the agitator hub, directs the water-chemical mixture outward across the tank bottom. Reaching the tank wall, the fluid mixture tends to rise but is redirected back to the center by a horizontal baffle on the tank wall. In this manner, a rolling current pattern is established.

Water chemicals and sludge are kept in intimate mixture for maximum precipitation. A very effective sludge blanket is formed and maintained in suspension. Sludge and heavy particles settle to the bottom, clarified water is drawn off the top of the tank.

In addition to the extreme simplification of agitator installation, the design of the agitator arm, which includes a number of supplementary jets that drive precipitated sludge outward from the center of the tank, has greatly reduced the need for baffling within the precipitator tank. This also contributes to cost reduction in the original installation.

General areas of application of the new equipment are in pretreatment of water for use in municipal, industrial, and public utility plants.

Colloidair Separator

A detailed bulletin (4772) on the Colloidair Separator for the processing of liquid wastes in a wide range of applications has been issued by its manufacturer, the Permutit Co., a division of Pfaudler Permutit, Inc., New York City. A compact, automatic system needing almost no personal supervision, the Colloidair Separator is adapted for low-cost operation in paper mills, meat packing and rendering plants, sugar refineries and in various other kinds of industry. It separates and recovers wastes, rendering them fit for safe disposal or reuse, and is especially suitable in operations requiring separation of suspended or colloidal solids from liquids or for removal of oils or greases from liquids.

Reliance Electric & Engineering Co.

The first complete of solid state regulators and exciters for variable speed drives has been announced by Reliance Electric & Engineering Co. of Cleveland, Ohio. The manufacturers state that these new solid state devices, using silicon controlled rectifiers and diodes in place of tubes, achieve precise motor control, $^1/_{10}$% regulation at base speed, with response times up to twice as fast as tube-type regulators.

For additional information, write Reliance Electric & Engineering Co., Cleveland 17, Ohio.

Research-Cottrell, Inc.

Large power savings are made possible by a new engineered service announced by Research-Cottrell, Inc., for converting mechanical and tube rectifiers for electrical precipitators to silicon rectifiers. Payout time for the conversion can be cut at least in half by the new engineered service.

Maximum economic benefits of the conversion are realized by careful evaluation of the complete control system under the new Research-Cottrell engineered service. Large power savings in the control circuit yielded by the engineered conversion save enough over annual mechanical rectifier power costs to pay for the initial cost plus power costs of the silicon rectifier in a minimum of time.

Shawinigan Resins Corp.

A new 12-page booklet describing the physical properties and suggested uses of the firm's full product line has been published by Shawinigan Resins Corp., Department DP, Springfield 1, Mass. The new Product Reference File, which is an expansion of a shorter work, presents data on Formvar, polyvinyl formal, Butvar, polyvinyl butyral, Gelvatol, polyvinyl alcohol, and Gelva, polyvinyl acetate, resins, emulsions, and spray-dried powders.

SOUTHWORTH MACHINE CO.

The Southworth Machine Co., manufacturer of equipment for the graphic arts, paper mill, and materials handling industries, announces the appointment of **Donald P. Jones,** Simsbury, Conn., as its Eastern sales manager.

SPROUT WALDRON & CO., INC.

The availability of a new Pneu-Pac® bulletin (211–B) describing compact positive and negative pressure pneumatic systems for car, truck or bin unloading in both stationary and portable units is announced by Sprout, Waldron & Co., Inc. The bulletin gives dimensional information and capacity data of interest.

A. E. STALEY MFG. CO.

George A. T. Moore has been appointed manager of sales to the paper, corrugated, building materials and related industries for the A. E. Staley Manufacturing Co., according to an announcement by L. E. Doxsie, vice-president.

George A. T. Moore, A. E. Staley Mfg. Co.

STOWE-WOODWARD, INC.

Neenah Plant

More than 200 executives representing the top paper mills of the nation gathered in Neenah, Wis., recently (May 2) for an inspection tour of the new Stowe-Woodward, Inc., roll covering plant.

Although Stowe-Woodward has maintained manufacturing facilities in Neenah since 1954, the new installation incorporates the latest techniques and design for the processing of rubber covered rolls. It is also the third Stowe-Woodward plant to offer suction press roll covering service to its customers. It will serve customers in the Fox River Valley region and mid-western states.

Stowe-Woodward plant at Neenah, Wis.

Stowe-Woodward also maintains division and manufacturing plants in Newton Upper Falls, Mass., and Griffin, Ga. The corporation is celebrating its 75th anniversary this year.

Staff

James P. McNamee has joined the Research and Development Dept. of Stowe-Woodward as roll development manager. He will be responsible for new product development as well as product improvement for this 75-year-old manufacturer of industrial rubber rolls.

TEXAS GULF SULPHUR CO.

Texas Gulf Sulphur Co., 75 E. 45th St., New York, N. Y., leading producer of crude sulfur as mined by the Frasch hot water process, has prepared a revised edition of "Modern Sulphur Mining" which was last published several years ago. This edition updates statistical data and latest developments in both production and distribution of this essential commodity.

U. S. STONEWARE

The new protective coating, trade named Tyzin, a sacrificial metal coating offering excellent resistance, with or without a topcoat, to organic or inorganic solvents, fresh or salt water, oils and greases has just been announced by The United States Stoneware Co., Akron, Ohio. A 2 to 3-mil thick film, obtainable in a single application, provides an excellent surface also for all standard Tygon vinyl topcoats or epoxy topcoats.

WALLACE & TIERNAN, INC.

Wallace & Tiernan, Inc., 25 Main St., Belleville, N. J., has just published a 20-page, fully illustrated catalog (520.100) describing its complete glass-tube Varea-meter line. The catalog contains information on industrial applications of rotameters, features of the entire line, and details of the several tube and float types available. In addition, it lists selection and ordering data. The industrial user can quickly select the meter for his exact purpose by merely consulting the charts provided.

WESTINGHOUSE ELECTRIC CORP.

Static, regulated adjustable-speed drives called Reactifier drives, which operate from a.c. power source, were furnished by the Westinghouse Electric Corp. to drive machinery which makes single- and double-faced corrugated board sheets.

In this application, two 60-hp. Reactifier drives are used with the section of corrugating machine which produces the corrugated sheet and combines it with a top facing sheet. A 100-hp. unit is used with the section of the machine where the bottom facing sheet is applied to the two single facing sheets. The chief advantages of the drive units, for this application, are reduced maintenance, less floor space, less weight, higher efficiency, good regulation, ease of installation, and personnel safety.

General

SEVENTH ANNUAL PACKAGING EXHIBITION

The Seventh Annual Packaging Exhibition will be held in London, Sept. 5 to 15, 1961. The exhibition will cover the field of packaging—machines, materials, containers, and packaging handling. Over 300 exhibitors, including some 70 foreign manufacturers are planning to participate. Additional information may be obtained from International Packaging Exhibition, Engineering in Britain, 9 Malcolm Road, London, S.W. 19.

GLOSSARY OF PACKAGING TERMS

The Packaging Institute announces the availability of the Third Edition of its "Glossary of Packaging Terms" now a part of Federal Standard 75 by reference.

The third Edition of the Packaging Institute's "Glossary of Packaging Terms" is a joint project of various agencies of the United States government including the Army, the

Navy, and the Air Force working in conjunction with a large number of participants from private industry through the instrumentality of the Packaging Institute of New York City.

Copies of the Edition of the Packaging Institute's Glossary of Packaging Terms printed in loose-leaf form in accordance with Government standards to fit standard three-ring binders are now available at $3.50 per copy through the Packaging Institute, Inc., 342 Madison Ave., New York 17, N. Y.

India

Rayon Pulp Plant

India's Minister of Industries, Manubhai Shah, laid the foundation stone of India's biggest rayon grade pulp plant at Kalsur on April 30. Work on this Indo-French joint venture worth $21 million, is expected to be completed within two years. After completion the Great Mysore Rayon Grade Pulp and Paper Mills will manufacture 110 metric tons of rayon grade dissolving pulp per day. This capacity is likely to be expanded to 350 metric tons per day in two stages of about three years' duration each.

Lighting Handbook

A section of the official Lighting Handbook of the Illuminating Engineering Society, showing the minimum recommended levels of illumination for every task approved by I.E.S. Council, has been newly reprinted and made available to manufacturers and electric utilities. Entitled "Recommended Levels of Illumination," the booklet replaces all previous publications on this vital subject. I.E.S. is the recognized authority on recommended lighting levels, as well as on other questions concerning illumination.

Reprinting sections of the official I.E.S. Lighting Handbook has been extremely limited in the past. The new reprint, which is 16 pages long, may be obtained at 20¢ a copy (with discounts for greater amounts) from the Illuminating Engineering Society, 1860 Broadway, New York 23, N. Y.

Ontario Research Foundation

Sulfite Recovery Process

W. R. Effer, research associate of Ontario Research Foundation, Toronto, officially "unveiled" a new process that could profoundly affect much of the North American pulp industry at the meeting of the Canadian Pulp and Paper Association held at Saranac Lake, N. Y. In a paper co-authored with Dr. H. B. Marshall, director of the Foundation's Department of Chemistry, Mr. Effer detailed a method developed by ORF for recovery of ammonia and sodium from sulfite pulping wastes. This development has already been described by some technologists as "challenging the present processes used in the whole of the $850,000,000 U. S.-Canadian sulfite pulp industry."

The new process was developed by ORF in a research program for J. F. Pritchard and Co., Kansas City, Mo., to which patent rights have been assigned. Basically it involves an ion exchange procedure for the removal of ammonium or sodium ions from sulfite pulping liquors, and their subsequent regeneration. This means that ammonium and sodium-base sulfite pulping processes may thereby become competitive with the sulfite processes now based on calcium compounds. The new process would help to reduce problems of stream pollution, and also simplify methods for the recovery of valuable lignosulfonic acid by-products.

Most sulfite pulping plants today use calcium chemicals because they are cheaper. Such chemicals, however, create pollution problems and make more difficult the utilization of effluent for the manufacture of by-products. It is believed that the ORF process may reduce the cost differential to the point where ammonium or sodium sulfite pulping can become completely competitive—perhaps even economically advantageous. If this proves to be true in actual plant practice, the North American pulping industry could be revolutionized.

One of the important features of the process is a "conditioning step" invented by ORF scientists, whereby troublesome ions of calcium, magnesium, and iron are removed before effort is made to recover ammonium or sodium ions. This makes possible subsequent steps leading to the desired chemical recovery goals. The entire process is covered by Canadian pat. 618,158, issued to Ontario Research Foundation on April 11 of this year.

Russia

The Forest Products Division of the Business and Defense Services Administration in cooperation with the American Paper and Pulp Association has released a detailed report on East Europe's pulp and paper industry; namely, "The Pulp, Paper and Paperboard Industry of the U.S.S.R. and European Soviet Bloc Countries." The study gives a history of the growth of Russia's industry, an evaluation of its raw material resources, present production and expansion plans, as well as an analysis of the industry's future role in world trade. Soviet Block country data are also given.

Copies of the report are available upon request from the American Paper and Pulp Association.

Southern Pulpwood

More than 23½ million cords of pulpwood—an all-time high—were cut in the South during 1960, according to a recent report of the Forest Service, U. S. Department of Agriculture. The harvest, which was 4% greater than in 1959, supplied 57% of all wood used by the Nation's pulpmills during the year.

Pulping capacity in the South continues to rise. It increased from 46 thousand tons of pulp per day in 1959 to more than 50 thousand tons last year. Six new mills are in prospect.

Georgia was again the South's leading producer, harvesting 4.9 million cords. Alabama cut 3 million cords, and North Carolina, South Carolina, and Florida each cut more than 2 million.

More than 12% of the wood is delivered to the mills in the form of chips. These are mainly supplied by other wood-using plants. At least 896 sawmills, veneer mills, and other forest industries are currently equipped with chip-making machinery.

The report, titled "Southern Pulpwood Production

Pulpmill Capacity and Pulpwood Production by State, 1960

State	Number of mills	Mill capacity in tons of pulp per day	Pulpwood produced thousand cords Round-wood	Pulpwood produced thousand cords Resi-dues	Three leading counties
Ala.	9	4,693	2,594	426	Baldwin, Mobile, Choctaw
Ark.	4	2,525	1,216	340	Union, Grant, Ashley
Fla.	10	8,430	1,923	177	Putmam, Hamilton, Nassau
Ga.	12	8,085	4,410	496	Ware, Camden, Wayne
La.	10	5,765	1,646	211	Union, Winn, Bienville
Miss.	7	3,093	1,775	199	Clarke, Jackson, Jasper
N.C.	5	4,130	1,888	386	Columbus, Onslow, Brunswick
Okla.	1	90	39	14	McCurtain, LeFlore, Pushmataha
S. C.	5	4,840	1,901	289	Colleton, Fairfield, Newberry
Tenn.	5	2,357	354	8	Monroe, McNinn, Morgan
Texas	5	2,565	1,134	292	Jasper, Polk, Shelby
Va.	8	3,740	1,715	118	Brunswick, Buckingham, Amherst
Total	81	50,595	20,595	2956	

1960," was prepared by the U. S. Forest Service in cooperation with the Southern Pulpwood Conservation Association, Atlanta, Ga. Copies are available from the Southeastern Forest Experiment Station, Asheville, N. C., or from the Southern Forest Experiment Station, New Orleans, La.

Wisconsin

An estimated 40 million dollars was spent by Wisconsin's pulp and paper industry during the last 12 months for expansion programs to retain and expand national and world markets.

At the same time, the industry's employment in the state has remained at the same level as a year ago, despite the recession which has caused numerous job declines in other industrial fields.

These facts were pointed out at the annual meeting of the Wisconsin Paper Industry Information Service by the group's general chairman, M. J. Schulenburg. The group is an association of major pulp and paper manufacturers in Wisconsin.

Mr. Schulenburg, director of public relations for Kimberly-Clark Corp., Neenah, said the expansion projects included the completion or start on the installation of six new paper machines. In some cases, this new equipment will increase productive capacity by as much as 25%. The new equipment was added by Consolidated Water Power & Paper Co. of Whiting, Kimberly-Clark at Niagara, Nekoosa-Edwards Paper Co. at Nekoosa, Wausau Paper Mills Co. at Brokaw, Nicolet Paper Co. at De Pere, and Charmin Paper Products Co. at Green Bay.

Additional millions of dollars were spent by other paper firms to rebuild existing machinery and for other modernization and expansion purposes.

Regarding employment, the total for the industry in Wisconsin stood at 39,200 in March, a gain of 100 over a year ago rather than a decline such as other industries have experienced. The paper industry in Wisconsin continues to rank first among the nation's 42 paper producing states.

Wisconsin production of pulp, paper, and paperboard came to more than 3.5 million tons in 1960, one-tenth of the total for the United States.

Dollar sales were $850,000,000. The significance of this volume to Wisconsin's economy is illustrated by the fact that 1959 sales of Wisconsin milk totaled $560,000,000.

The present employment of 39,200 in Wisconsin, represents 9% of the manufacturing employment in the entire state. There are additional thousands employed in allied and supporting industries, such as those producing pulpwood and paper machinery.

The average weekly earnings for the state's paper industry production workers are more than $100, plus an estimated $20 to $25 in fringe benefits. The industry's annual pay roll in the state is about $225,000,000.

The paper firms have a capital investment in the state of almost $900,000,000. Annual taxes amount to $105,000,000.

Printing Process

The Curtis Publishing Company has announced the development of a new printing process known as "deep value reproduction," utilizing materials and new techniques especially suited to recently developed high-gloss inks.

This combination of specially formulated papers and new inks prints with an eye-pleasing, soft gloss, and gives depth and realism to color reproduction by eliminating glare distractions.

Effective immediately, all four-color advertisements in *The Saturday Evening Post* are being printed by the deep value reproduction process. Production capacity of the newly formulated papers has been increased so that two-color and black and white advertisements will also soon be printed with the new papers and inks.

Post advertisers will benefit materially from the new process because it is highly pleasing in its visual effect, Curtis officials said. When compared with ordinary color printing, deep value reproduction shows a new clarity of color that enhances four and five color printing. Photoengravers will now realize the maximum potential in process printing because they can achieve the subtleties and nuances present in the original art work. Dark colors are rendered rich and velvet in tone; lighter colors come up sparkling and clear; powerfully saturated colors, such as red, appear full and glowing.

Leon Marks, vice-president and director of manufacturing, said the new paper characteristics are the result of research by the company's wholly-owned papermaking subsidiary, New York & Pennsylvania Co., Inc., one of the nation's largest producers of magazine paper.

"Our papermakers have long sought papers that together with the new inks would give us a reproduction with soft, natural tones, yet with just the right amount of sheen to bring out all the highlights," said Mr. Marks. "Deep value reproduction is the answer. It gives a result not unlike that of a quality photograph on fine portrait paper."

"We feel that fidelity of reproduction, purity of tones, and uniformity are very important in producing mass-circulation magazines. The new process and these materials enable us to maintain the high standards of printing quality that we have always stressed at Curtis."

OBITUARIES

Robert Walter Wurst, Jr.

Robert W. Wurst, Jr., District Sales Manager of Pennsalt Chemical Corp., Industrial Chemical Division, died on April 16, 1961, at Decatur, Ga.

Mr. Wurst was born in Chicago, Ill., on June 24, 1920, and studied metallurgy at Illinois Institute of Technology. Prior to joining Pennsalt in 1951 he was employed by Fansteel Metallurgical Co., and Armour & Co.

He was president of the Atlantic Chemical Sales Club, the AATCC and the Technical Association of the Pulp and Paper Industry. He is survived by his wife, the former Charlotte Eaton, two sons, Steven and Jamie, and his parents.

Edgar Gilliam Putnam

Edgar G. Putnam, director and founder of Fiber Research, Seattle, Wash., died in Seattle on June 24, 1961.

Mr. Putnam was born in Tacoma, Wash., on July 12, 1909, and studied structural engineering at the University of Washington.

Prior to founding Fiber Research he was employed by the Austin Co., W. C. Nickum & Sons, and Puget Sound Pulp and Timber Co. He was also self employed as a consulting engineer.

Mr. Putnam became a member of the Technical Association of the Pulp and Paper Industry in 1956.

DIVISIONS AND COMMITTEES

Reports of Activities

Authorized Committee Assignments

The following new committee assignments were made during June, 1961. The total number of assignments now active in the 63 TAPPI technical committees is about 360. An identifying number is given by TAPPI Headquarters to each work assignment made by a committee chairman and approved by the appropriate division chairman. Assignment numbers should be requested for *all* activities of technical committees A separate series of numbers is reserved for each of the technical divisions.

Assignment no.	*Committee*	*Title and objective*	*Committeeman in charge of assignment*
		CORRUGATED CONTAINERS DIVISION	
3005	Steering Council	"Standard Terminology." To develop a catalog of words and terms used in the corrugated containers industry and which need standard descriptions.	R. W. Buttery
3006	Process and Quality Control	"Organized Training of Quality Control Men in Plants." Outline the training programs used by various box plants for quality control men.	Sidney Rubenstein
3007	Raw Materials	"Preparation and Storage of Corrugator Adhesive." To summarize proper procedure for preparing adhesives from various published data and experiences and proper storage.	M. L. Hamilton
		ENGINEERING DIVISION	
4032	Fluid Mechanics	"Subcommittee on Membership and Publicity." To encourage membership of interested parties in the Fluid Mechanics Committee. To make TAPPI membership more aware of activities in the field of fluid mechanics.	K. B. Latimer
4033	Electrical Engineering	"Power Requirements for Coaters." To determine HRL and RDC constants for the various type of coater drives.	J. V. Cundelan
4034	Electrical Engineering	"Service Factors for Gears Used on Equipment in the Paper Industry." To review present AGMA standards for paper industry equipment.	J. V. Cundelan
4035	Electrical Engineering	"Power Requirements of Fan Pumps." Arrive at a method for determining horsepower requirements of fan pump drives.	J. V. Cundelan
4036	Electrical Engineering	"Sectional versus Lineshaft Drives." To make an economic evaluation of these two types of drives.	J. V. Cundelan
4037	Maintenance Engineering	"Mill Experiences with Dissolving Tank Operation." To summarize industry experience with respect to operating, construction, and maintenance of dissolving tanks.	J. J. Yirek
4038	Electrical Engineering	"Density Control on Winders." To determine the pros and cons of roll density control on machine room winders and paper converting rewinders. To obtain information from machine builders in order to formulate a suitable questionnaire to be distributed to users through TAPPI channels.	L. W. Porter
4039	Corrosion	"Recommended Procedures for Lining Pulp Digesters with Stainless Steel Weld Metal Overlay." Develop standards for the installation of overlay for pulp mills to employ in setting upon contracting work and for contractors to employ in installing overlay.	R. C. Stamm
		PULP MANUFACTURE DIVISION	
6006	Deinking	"Collection and Classification of Information of Deinking Contaminates (CCIDC)." Involves request for funds to have work done.	A. Altieri
		RESEARCH AND DEVELOPMENT DIVISION	
7005	Fundamental Research	"APPA-TAPPI Fall Research Conference." To hold jointly sponsored conference (1961).	
8022	Pulp Testing	"CPPA-TAPPI Joint Task Force." To revise T 224 sm Laboratory Processing of Pulp-Ball Mill Method, and the Canadian Standard C_3 (both methods are the same).	G. I. D. Cameron
8023	Precision	"Standard Method for Statement of Precision in TAPPI Standard Methods." Preparation of new proposed method with above title.	C. A. Bicking
8024	Precision	"Standard Method for Rejection of Outlying Test Results." Preparation of a new proposed method with above title.	C. A. Bicking

Coating and Graphic Arts Division

Graphic Arts Committee

The meeting was called to order by H. J. Connell at 9:20 a.m. at the Commodore Hotel, Parlor A, on Feb. 20, 1961. He called upon Richard Trelfa, Division chairman, for his remarks. Mr. Trelfa read a telegram from C. A. Morton, chairman of the Graphic Arts Committee, in which he apologized for not being able to attend the meeting. Mr. Trelfa then announced that Mr. Morton had resigned as chairman of the committee but stated that he would remain vice-chairman of the Division.

Mr. Trelfa then reported on the meetings of the Technical

Operations Committee and the Joint Advisory Council. He explained that a new numbering system had been approved and that blocks of numbers will be issued to the Divisions. This system will start in 1961 and the committee projects will all be given new numbers according to the new system.

The current projects covered by the new numbering system are:

The Proof Press and Printing Quality—*Chairman:* Oppen (No. 1004)
Definition of Terms in the Paper Printing Area—*Chairman:* Oppen (No. 1005)
Surface Strength Evaluation—*Chairman:* Glassman (No. 1006)
Transfer and Penetration Aspects of Ink Receptivity—*Chairman:* Walker (No. 1007)
Graphic Arts Committee Operating Manual—*Chairman:* Connel (No. 1008)
Monograph on Printing—*Chairman:* Rogers (No. 1009)

Mr. Trelfa then went on to explain that all monographs were subject to the approval of the Technical Operations Committee both in content and timing. Since each publication of a Monograph costs TAPPI approximately $8000, it is imperative that they be budgeted. He suggested that the Graphic Arts Committee, within the next 2 months, supply him with a critical review of all monographs (already in print, in process, or in committee), so that he might present this information at the next meeting of the Technical Operations Committee which will be early in June of this year. The Technical Operations Committee will thus have the overall picture of monograph projects and will be able to fit the projects within the budget provided by the Executive Committee of TAPPI.

Mr. Trelfa urged that the preparation of the Manual for the Operation of the Graphic Arts Committee be completed as rapidly as possible. He requested that the project, which has already been approved by our committee, be fitted into the Manual for the Guidance of Technical Divisions and Committee approved by the TOC. He indicated that it was not mandatory but highly desirable, and that if at all possible the existing manual should be modified by the insertion of color coded sections. TAPPI Headquarters will advise the committee of the color assigned to it.

The Council had discussed the matter of extending complimentary registrations at the conferences but the suggestion was defeated. It was reported that a special committee will be set up to review a project dealing with relative humidity and temperature.

While there had been no meeting of Division officers to discuss Project Grant No. 168—Transfer and Penetration Aspects of Ink Receptivity (Project 1007), there had been some exchange of correspondence and there seemed to be considerable interest.

Mr. Trelfa pointed out that the objectives of TAPPI are to disseminate knowledge among the members. He felt that there was a tendency for too much intracommittee communication with not enough data going out to the general membership. The graphic arts meeting at the Benjamin Franklin Hotel, Philadelphia, on March 17 was mentioned.

Before closing, Mr. Trelfa introduced J. E. Wilber who is secretary of the Coating and Graphic Arts Division. He also announced that our TAPPI president, J. R. Lientz, had appointed H. J. Connell as chairman of the Graphic Arts Committee.

Following Mr. Trelfa's remarks, M. C. Rogers read the minutes of the committee meeting held in New York 1960. These minutes were adopted on motion of W. C. Walker, seconded by George Mead.

Mr. Connell then announced that Dr. Rogers had resigned as scretary and Mr. Walker as technical officer. He announced the appointments of J. R. Gunning as secretary and Alex Glassman as technical officer.

The subcommittee chairmen were announced as follows:

Alex Glassman, Surface Strength
W. C. Walker, Ink Receptivity
F. C. Oppen, Printability
J. H. Wing, Program and Papers
M. C. Rogers, Editorial
L. E. DeLauter, Publicity
W. B. Redpath, R.C. Methods Liaison

Mr. Connell read Mr. Morton's report for the year 1960. The Chairman then called for the subcommittee reports.

1. *Monograph on Printing*—M. C. Rogers. Mr. Trelfa has said that, although TOC is generally in favor of Monograph, they have to be timed and fitted into the budget. Nevertheless considerable work has already gone forward. The master outline has been drawn up and finished manuscripts have been received from over half the 25 authors contacted. A detailed report on the monograph was requested so that official approval could be secured. Further details will be discussed at a subcommittee meeting later on in the week.

2. *Surface Strength*—Alex Glassman. This assignment has been carried on under Project Grant No. 166 by Lehigh University with very good success. It is believed that a satisfactory although possibly tentative procedure has been developed for the use of I.G.T. instrument and this will be reported Wednesday morning, February 22, at the Graphic Arts Session. A subcommittee meeting will be held at 4 p.m. February 20 to discuss this work before the presentation.

3. *Ink Receptivity*—W. C. Walker. A subcommittee meeting will be held at 9 a.m. on February 21. This work was sponsored at Lehigh University in 1959 when it was requested that measure of the ink transfer parameters and the nature of these parameters be determined. There are at present five suggested areas for work and it is requested that there be a further appropriation so that work may continue. It was pointed out that details with respect to the last appropriation have not been received as yet and that this matter should be straightened out as soon as possible. Connell agreed to handle. There must be a reassessment of the problem to determine what has been accomplished and what the program should be in the future.

4. *Printability*—F. C. Oppen. Three authorized committee assignments have been handled by this subcommittee. Number 616, Survey of Letterpress Proof Press techniques, is considered finished. Number 572, Definition of Terms in the Paper Printing area, is a parallel project to one being carried on by the Research and Engineering Council. That organization is reported to have finished their draft and Mr. Walker was requested to ascertain whether their work had yet been distributed.

Project Number 346 The Proofpress and Printing Quality, has been completed to the point where it can be submitted as a Routine Control Method for smoothness. It was requested that Mr. Redpath take this question under advisement and see that it reached the R.C. Methods Committee. The first draft of a method using the I.G.T. instrument has gone to Committee and a second draft is in preparation.

5. *Program and Papers*—J. H. Wing. Five papers have been arranged for the morning session on Feb. 22, 1961, and five papers for the afternoon session. Mr. Wing was very satisfied with the cooperation he had received and stated that in his opinion the papers were of a high caliber.

6. *Publicity*—L. E. DeLauter. There was some trouble early in the year in finding a basis for liaison with TAPPI and Fuller and Miehle but these difficulties have been cleared away. There was good coverage on the convention and the cooperation of the subcommittee chairmen was solicited for further releases. To facilitate this, a reminder will be mailed to the subcommittee chairmen each three months.

7. *Routine Control Methods Liaison*—W. B. Redpath. The method of using the Vandercook proofpress as a smoothness testing instrument will be passed on to the R.C. Committee as quickly as possible.

8. *Air Leak Smoothness Subcommittee.* This work was

done under the chairmanship of T. W. Lashof and was published last year.

9. *Smoothness and Compressibility*—H. W. Verseput. Mr. Verseput was not present to make a report on this project.

Old Business

The chairman announced that the need for an operating manual for the Graphic Arts Committee was recognized and that work had commenced on its preparation. He stated that the manual used by the Coating Committee would be used as a model and that the Steering Committee would do everything possible to get it printed and out to the membership in the near future.

He also pointed out that the membership roster of the committee was not up to date and requested all members, both old and new, to send a letter to the secretary stating their intention to serve on the committee and outlining their specific fields of interest. This request provoked some discussion and the thought was expressed that it would be more efficient if a form were sent to all members and prospective members for them to complete and return to the secretary. J. R. Gunning agreed to handle this matter.

New Business

A letter was read from Mr. Carlgren of William F. Hall Co., Chicago, in which he stated there was a very great need for test methods which would predict print quality and press performance. The conventional methods of testing are obsolete for the new high-speed presses and TAPPI should develop tests which will ensure perfect paper at all times.

Considerable discussion followed in which Dr. Rogers said that it would appear that the writer did not appreciate what has been done and that in any event the problems to which he referred were well recognized. Mr. Walker stated that the papermakers need more help from the printers while Mr. Glassman expressed the opinion that with sufficient effort tests can be developed by the printer for his specific presses. Mr. Morris pointed out that you could not deal in generalities but you had to know the properties of the press involved. Mr. Mead said he was glad to see a pressroom sufficiently interested to write a letter of this sort but pointed out that when a papermaker gets into trouble he has nobody to go back to for an answer. This points up the great need for the study for fundamentals. The discussion closed with Dr. Rogers undertaking to talk with Mr. Carlgren.

The question was raised of whether the Graphic Arts Committee should participate in the 1962 Testing Conference. Miss Jacqueline Fetsko and Jim Wing expressed the fear that since it is hard to get good papers on the graphic arts theme there might not be enough for our already established programs. There were two suggestions, one by Alex Glassman who thought that we might contribute a few papers of a rather detailed type while Dr. Rogers thought the best contribution would be a panel discussion. It was decided that Mr. Connell would talk to W. R. Willets on this matter.

H. W. MacKinney of I.B.M. suggested that the Graphic Arts Committee might consider a project in connection with the preparation of specifications for paper for magnetic printing. He pointed out that the banks are doing a lot of their sorting using this process and that the forms they use can be printed either by a commercial printer using lithography or letterpress or they can be done on office machines. The American Banking Association has apparently given the matter some thought and has said that embossment and depth of black are two factors of great importance but are difficult to measure. As far as Mr. MacKinney knows very little work has been done on the definition of a suitable paper. In connection with safety coatings, nonblocking is an important characteristic. Besides the magnetic systems optical reading characters are coming in to more use and these, of course, are very affected by spots, specks, or voids. Still another automatic device is the automatic translation of foreign languages. Mr. Walker pointed out that we were discussing printing smoothness and the measurement and control on the press to prevent embossing which was already being covered by a subcommittee and that this suggestion should be drawn to their attention. Mr. MacKinney was asked to write up his suggestion and submit it in writing to the committee.

A letter was read from Jack Winchester announcing a special meeting to discuss whether a TAPPI project should be inaugurated to study curl of paper and board. The feeling was expressed that while curl influences the graphic arts very greatly, this particular study would not come under the terms of this committee. However, there were many present who disagreed with this view and it was agreed that the Graphic Arts Committee would have representation at the meeting.

The meeting closed at 12 noon by the chairman announcing a Steering Committee meeting at 9:00 a.m. on February 23.

J. R. Gunning, *Secretary*

Corrugated Containers Division

Engineering Committee

The meeting was called to order at 9:00 a.m. at the Pittsburgh Airport Hotel, May 9, 1961, by committee chairman, A. Richardson.

The minutes of the previous meeting of Feb. 20, 1961, at New York were approved as submitted. Motion entered by R. D. Merrill and seconded by F. Westfall.

Chairman Richardson recognized and introduced the guests attending.

New Members. Chairman Richardson announced the resignation of R. C. Berger from the Engineering Committee, and the proposal replacement by J. H. Roos of the same company (General Electric Co.)—the proposal was discussed and Roos elected to membership (motion by C. D. Nitchie, seconded by L. H. R. McGill).

Also elected to membership was W. A. Nikkel of West Virginia Pulp and Paper Co., Covington, Va. The secretary was instructed to prepare letters of welcome to these new members.

Status Report on Fall Meeting—San Francisco. Discussion was held on subjects and speakers to be furnished by Engineering Committee at the fall meeting which has a revised schedule date of Sept. 6–8, 1961.

1. C. D. Nitchie has reported that Phil Paul of Flintkote Corp. has been contacted and has consented to speak of the meeting.

2. L. H. R. McGill reported on progress in developing a paper on the subject of rotary die cutting and will be working in conjunction with Don Phillips of Longview Fibre Co., on subject of serrated blade versus standard platen-type die cutting.

3. C. D. Nitchie reported on progress of web alignment subject—with material provided through assistance of Larry Roberts. Presentation to be made by Todd Snyder of United Containers if possible.

4. R. O. Merrill reported that progress is being made on subject of steam generating systems and condensate return equipment. It was pointed out that the papers being prepared should be submitted by June 15.

Engineering Committee Project No. 776. Frank Westfall submitted a final report on Project No. 776—on recommendation of a standard method of determining takeup ratio. Additional discussion was made on the subject and it was concluded that in view of the many variables, there was no simple, reliable method available for measuring takeup ratio with consistent results.

The secretary was instructed to forward the compilation of data and series of reports to the Steering Council.

Recuting and Heat Testing of Corrugator Rolls. Open discussion on the above subject was made with reference to experience from members present and effects on (1) improved quality and (2) improvement on takeup ratio. The subject was tabled till the next meeting so that additional time would be available to report on results.

Box Plant Project—Machining Selection and Drives. A listing of recommended machinery required for the proposed box plant, as prepared by C. D. Nitchie and A. Richardson, was discussed with emphasis on the following: (1) arrangement of single-facer location, (2) roll conveyors versus dollies, (3) automatic order changing, (4) slitters—triplex versus duplex and 4-bar slitter.

A suggested list of electrical drive specifications for the selected machinery was submitted by L. W. Kutz with discussion on various points.

Continuation of box plant project—new subjects to be covered: (1) material handling—T. Haire and R. C. Hutcheson; (2) area/operation and machinery layout—H. W. Moser.

Future Commitee Meeting. It was announced that at the meeting in San Francisco in the fall, the Engineering Committee would have two sessions—9 to 12 a.m. and 2 to 5 p.m. on September 5, prior to the General Conference.

There being no further business, the meeting was adjourned at 4:30 p.m.

L. W. Kutz, *Secretary*

Industrial Engineering Committee

Minutes of meeting held May 19, 1961, at R. S. Owen's office Chicago, Ill.

Minutes of the February Meeting at New York. Secretary Spraque read the minutes from the last meeting.

Chairman Owen announced that A. J. Dannerberg notified him in his letter of March 13, 1961 that he must, regretfully, resign from the committee. Chairman Owen also related that George Austin had notified him that he would be unable to serve as project chairman of "Definition of Terms."

J. C. Sprague was appointed chairman in Mr. Austin's place.

Executive Group Established. Chairman Owen announced the formation of an executive group within the committee composed of officers, activity chairmen, and past chairmen. This group will act in a committee policy and coordinating function.

Chairman Owen instructed Secretary Sprague to write C. H. Colton, N. H. McDonald, C. L. Prowdzik, and K. F. Gabhardt asking them to confirm their membership to the Industrial Engineering Committee.

D. D. Hall, vice-chairman of the Industrial Engineering and Materials Handling Committee (Engineering Div.) has asked Chairman Owen to help establish communications between our two committees. Secretary Sprague will send copies of our meeting minutes to Mr. Hall and will request that copies of their meeting minutes be sent to Chairman Owen.

February, 1962, Meeting in New York. The Production and Industrial Engineering Committees are to arrange the February, 1962, Corrugated Meeting. Jack Comly of the Production Committee will serve as Technical Program Committee chairman and has asked for suggestions for topics.

The Industrial Engineering Committee suggests the following: (1) A panel discussion on the pros and cons of incentives—and that L. C. Wightman of Hoerner Box be contacted who will recommend someone from his company to discuss the pro side of the qeustion. (2) An expansion of the talks previously given by C. B. Lawler and R. J. Buckley on waste programs.

A Measure of Productivity. L. C. Wightman, project chairman pro tem of "A Measure of Productivity," gave a report on his recommendations concerning the projects. He described the present measure used by the Fibre Box Association which consists of an average labor cost per MSF and average man hours per MSF. Mr. Wightman pointed out the inadequacy of such an average which gives no consideration of many variables making up these averages. He further outlined a proposed measure which would eliminate the effect of most variables on an RSC basis.

The group agreed that his recommendation seemed to answer the purpose of the project. The committee assignment proposal will be submitted as follows:

Title—A Measure of Productivity
Objective—To indicate the trend of productivity within an individual company compared to a group of companys.
Outline of Procedure—Develop proposed reporting system; request committee membership to send required information; consolidate information and review at New York meeting (1962).

When L. C. Wightman has completed his portion of the project, a new project chairman will be appointed.

Definition of Industrial Engineering Terms. The group discussed the project and agreed that the committee assignment proposal should be submitted as follows:

Title—Definition of Industrial Engineering Terms
Objective—Standardization of terminology
Outline of Procedure—Ask, by letter, for comment or exceptions to definitions listed in the Industrial Engineering Handbook; consolidate and submit proposal at New York Meeting (1962).

J. C. Sprague is project chairman.

Manual of Supervisory Training on Industrial Engineering Subjects. After some discussion it was established that the following would be included in the committee assignment proposal:

Title—Manual of Supervisory Training on Industrial Engineering Subjects.
Objective—To present outlines for supervisory training in industrial engineering subjects to supplement the work already under way by the Production Committee.
Outline of Procedure—Make a survey on what committee members propose or are using; consolidate and report recommendations at New York Meeting (1962).

R. J. Buckley is project chairman.

Industrial Engineering Approach to Control of Waste. The group in a general discussion, became interested in a project on waste control. It was finally agreed that through recommending a good waste program, our committee could provide a substantial service to our Corrugated Division.

Chairman Owen appointed L. C. Wightman as chairman of the project and the following was outlined:

Title—Industrial Engineering Approach to the Control of Waste
Objective—Recommendations for waste reduction
Outline of Procedure—Investigate what is being done in plants of committee members and propose a comprehensive program.

Other Discussion

1. All committee members are to receive complete membership list and addressed.

2. Due to the controversy in management concerning the pros and cons of incentives it was agreed that industrial engineers should take every opportunity to stress the desirable functions of incentives.

3. A discussion as to the loss of many I.E.'s to line management positions seems to establish two clear career lines for industrial engineers: engineering and production.

J. C. Sprague

Engineering Division

Mechanical Engineering Committee—Interim Meeting

The Mechanical Engineering Committee held an Interim Meeting at the Olde Coach Inn, Nashua, N. H., Thursday, April 27, 1961. A social hour was held from 12:30 to 1:00 p.m., luncheon from 1:00 to 2:00 p.m., and a regular business meeting followed. Chairman J. S. Mudgett presided. Seven members were present.

Chairman Mudgett called the meeting to order at 2:00 p.m. with appropriate remarks welcoming all members in attendance. The minutes of the February meeting were read and accepted as presented. The first order of business was outlining the program to be presented at the Engineering Conference to be held at the Shoreham Hotel, Washington, D. C., October 15 through the 19. There will be 3 hrs. time allotted for presentation of papers by this committee and the general outline of the papers are as follows:

1. *Formex Fabric on Paper Machines.* A. Mechanical Aspects—approx. 20 min.; B. Fabric Design—approx. 20 min.; C. General Discussion—approx. 20 min.

The presentations will be given by Messrs. C. Lee and R. Wagner of the Huyck Equipment Co., Milford, Conn. Mr. Givin read the outline of the mechanical aspects and fabric design portions of the presentation and stated that possibly slides would be available to coincide with the lectures. Chairman Mudgett stated the papers must be in TAPPI Headquarters by July 1, 1961, in order to have preprints made.

2. *Rolless Flo-Vac.* The author of this paper is still in question but will be presented by someone from West Virginia Pulp and Paper Co. The estimated time for this paper will be 30 min. There is no other information available at the present time on this subject.

3. *Skewed Roll Calender Stack.* The time required for this paper will be approximately 30 min. and Chairman Mudgett is working with Farrell Birmingham on this subject and stated that they will be glad to give the paper but must get clearance through their company officials. Chairman Mudgett gave a good presentation on samples of skewed roll application with considerable interest shown from the other members in attendance. It was left that Chairman Mudgett would be in contact with Farrell Birmingham for appropriate action to be taken on this paper and determination if it will be presented in the 1961 meeting or not.

4. *Mechanical Features of Continuous Pulp Systems.* Four short papers discussing the pros and cons of the system. This paper will be presented by representatives of the following companies: A. Black-Clawson—W. Herbert; B. Kamyr; C. Improved Machinery Co.—18-min. movie and presentation; D. Bauer Bros.—R. Goodman: paper and slides; E. American Defibrator—Mr. Logran. The time for the presentation will be 1 hr. and 18 min.

Ray DePan has completely lined this last paper up and given a very interesting presentation of the high lights of this paper. Ray stated that by June 15 he will have the names of the authors that are not listed. With the papers mentioned, a total time of approximately 3 hr. and 18 min. will be utilized, thus we of the committee feel that this should be a well-rounded and interesting session. The following is a list of papers and subjects that this committee has as a surplus and will either be used for fill-in if required, or presented at later meetings.

1. Mill experience with suction press installation.
2. Comparison of suction roll materials (bronze and stainless).
3. Ray DePan has discussed the possibility of a paper from Black-Clawson and The Mead Corp. regarding continuous freeness tester. It was finally resolved that this paper should be turned over to the Instrument Section Committee of TAPPI, E. W. Printz, Champion Paper Co., Hamilton, Ohio.
4. Farrell-Birmingham would like to present a paper on calendered roll crown calculations. It was decided that if it could be arranged, they could submit this paper in written form.

This committee decided to look to the future with mainly the 1962 meeting in mind for subjects that will stimulate added interest in the sessions and help to promote new ideas in the industry to the personnel. The following is a list of subjects that should have possibilities for this future meeting and we of the committee are sure that more interesting subjects will be added to the list throughout the year:

1. Discussion of supercalenders on paper machines. It was pointed out that this should be a wide open field in the industry and that there is tremendous work to be done and potential gained.
2. Screening problems in the industry. Mr. DePan brought up this subject and he feels that there is a tremendous amount of knowledge to be gained in this field.
3. Discussion and comparison of pulpers that are becoming available to the industry.
4. Deculators.
5. Converting and finishing equipment.
6. Mechanical barking.
7. Barking, ship storage, and logging operations. It was discussed in detail that a paper of this nature would be extremely interesting and in preparing the paper, a comparison of the South versus the North in its operations. It appears that new equipment is being made available for these operations very fast and methods of operations seem to be changing overnight. It was decided to have the secretary write Messrs. Starkweather and Hutchins to ascertain if a paper of this nature could be presented.

The finishing data still are very weak with no papers to be supplied in the near future. It was the feeling of those present that this committee should supply one paper for the 1962 meeting. The name of Robert Regers to head this subcommittee was discussed and he is to be notified. The name of John Eberhardt of The Beloit Iron Works was mentioned to be approached as a new member to work on this subcommittee.

Chairman Mudgett read the contents of a letter received from H. O. Teeple of TAPPI. In general this letter pointed out the regulations covering letter ballots for the approval of Technical Information Sheets and the mechanics of getting the sheets approved. Mr. Teeple also enclosed a résumé of the present status of the Mechanical Engineering Committee activities as TAPPI Headquarters records indicate. In light of the above mentioned, Mr. Taska is to send copies of data sheets to the committee members. These members are to be cast the written letter ballot for the approval of the Technical Information Sheets.

The Mechanical Engineering Committee wishes to thank the St. Regis Paper Co. for the social hour, luncheon and the interesting mill visitation that was conducted following the meeting of the committee.

R. P. Finney, *Secretary*

Process Instrumentation Committee

Joint Symposium—Green Bay. Chairman Prince expressed the thanks of the committee to Gar Eastwood and Carl Lindwall for handling the Process Instrumentation Committee part of the symposium. At Dick Gardner's suggestion this was extended to all the local people who took part.

Gar Eastwood reported a registration of about 200 for the symposium and 80 for the maintenance clinic. Approximately 50% were from Wisconsin. He will report later on the Management Workshop.

Dick Gardner stated that the Memphis ISA had requested

the 1963 Southeast ISA Conference and a joint Pulp and Paper Instrumentation Symposium. Herb Teeple stated that the subject of future joint meetings will be up for discussion at the June 26 meeting of the TAPPI Technical Operations Committee. Gar Eastwood will send a report to Earl Prince on the Green Bay Symposium. Earl will in turn report to TAPPI for consideration by T.O.C.

Letters of appreciation will be sent to ISA workers for the symposium.

Technical Information Sheet Subcommittee. Dick Gardner reported for the committee on:

1. Flow Symbols—T.I.S. Should be available soon. It will be quite similar to those used by ISA and C.P.P.A. Dick led a discussion on several points. By September 1 the tentative specification will be mailed to all committee members for comments, which will be due back before the Washington Conference.

2. Instrument Air Piping Materials (Kirkland) and Instrument Air Supply Requirements (Gardner). A questionnaire will be distributed to mills. Based on the results the subcommittee will propose how the project should be handled. This should be done at the Washington meeting.

Carl Lindwall was added to this subcommittee by Chairman Prince.

Projects.

Project No. 692: Herb Teeple advised that the questionnaire will be mailed in the next week or two. It will be pushed along so that results will be ready for a report in Washington. Earl Prince stated that Dick Friction will present this.

Consistency: A suggested project is a survey of consistency instruments similar to that handled by Bob Hurm on moisture (No. 775).

Another suggested project is "Economics of Instrumentation Installation."

Date Handling Computer Panel. Don Michel reported on the Chicago meeting and that the presentation will be ready for Washington. The title will be "Computer Control?" It will be moderated by Art Plummer. Topics will include economic justification and case studies. Harmon requested the inclusion of the definition of "Computer" as used here. Gardner added the same request for "Control." Don Michel will obtain abstracts from panel members and submit them with a summary to Herb Teeple for the preprint.

1961 Engineering Conference—Washington. The program will be:

Black-Clawson-Mead Freeness Paper
"Controlling the Variables," by W. A. Wrase
"Report on Project No. 692," by Dick Friction
"Computer Control?," a panel

1962 Engineering Conference—Montreal. Tentatively we are counting on papers by Couture, Cross, and Pearson.

New Members. All members were asked to submit names of prospective new mill men members to Gar Eastwood.

Future TAPPI—ISA Symposium. Herb Teeple again reminded us of the T.O.C. meeting in June.

Chairman Prince reported a request by the Montreal ISA for the 1964 or 1965 meeting. Jacksonville has requested the 1962 meeting through ISA. Gardner stated the Memphis desire for it in 1963.

Bill Frair stated he is ISA Liaison man for ISA-TAPPI-CPPA. He is a member of all three. He advised that ISA has established the future meetings as follows:

1962—Jacksonville
1963—Montreal
1964—Southeast

Bill stated that two out of three meetings should be in the Southeast based on interest in that area.

Committee Appointments—Program. "Bird-dog" assignments to procure papers for consideration were appointed as follows:

1963 at Cincinnati—J. K. Powell, J. O. Overall, J. L. Good, W. J. Frair, and H. E. Kirkland.
1964 at Seattle—G. A. Charters, D. C. Michel, C. D. Lindwall, L. G. Good, and D. J. Morrissey.

TAPPI—Question-and-Answer Column. Herb Teeple reported Q & A will be published, but emphasis is now on committee activity, not including committee minutes which are published separately.

The general theme of the Washington conference is "Economic Solutions through Engineering." Five committee reports will be in the June issue of *Tappi.* Others should be published in July. Therefore, he needs an article on the Process Instrumentation Committee program.

Future Meeting. The next committee meeting will be during the 16th TAPPI Engineering Conference in Washington on Tuesday afternoon, Oct. 17, 1961. It will not be a luncheon meeting. The Process Instrumentation Committee program will be on Wednesday morning, October 18.

Paper and Board Manufacturing Divison

Fourdrinier Committee

The spring meeting of the Fourdrinier Committee was held in Monroe, La., in the Holiday Inn Hotel on May 18 and 19, 1961. The business meeting was called to order at 9:00 a.m. by Chairman Ralph Peters. The minutes of the winter meeting in New York were approved as read.

Project No. 635—"The Problems of High-Speed Machine Operation." A subcommittee composed of Peters, Mullins, Brown, and Kennedy met and discussed the final disposition of this project. It was their recommendation that this project be discontinued. This met with the approval of the committee.

Project No. 802—"Wet End Process Control." Mr. Hershey, the chairman of the subcommittee handling this project, reported on the progress of this work. He distributed first drafts of the proposed special report summarizing the results of answers by 103 mills to this extensive questionnaire on the current status of in-process control. The special report as drafted, contained both a general summary of the results and analysis of the results by type of mill, as well as detailed analysis of certain key questions. This draft was discussed and approved in general. Each member is to study his copy and submit any corrections and his ideas on the best method of presentation at TAPPI. This should be done before the end of June.

Project No. 792—"Suction Box Covers." In the absence of the chairman of this subcommittee, Mr. Coats reported on the progress. Certain materials have been selected for examination at the Appleton Wire Works for friction and wear characteristics. These samples are now being run. Mr. Morton is to prepare an interim report summarizing the status and plans on this project to be submitted before the next meeting.

The subject of curl, which had been brought up before by the Joint Advisory Committee on Printability Research, was the subject of a meeting during the Coating Conference in Buffalo. This meeting was composed mainly of the Graphic Arts Committee, and they found a lot of interest in this subject. They apparently felt the same as we, that fundamental research was necessary. A recommendation is being made to the Technical Operations Committee, that a research project be sponsored in this field, perhaps in the form of a fellowship. The committee decided that it would like to cooperate in the work on this project.

Mr. Spencer has requested, by letter, that consideration be given to couch pit design as a Fourdrinier Committee project. Messrs. Mullins and Coats were appointed a sub

committee of two to investigate the information which is available on this subject, and whether this should be taken on as a project. It was agreed that clarification in this field would be desirable.

PIMA is disbanding the Drier Felt Committee and TAPPI has asked the Fourdrinier Committee to take over any of this work which we deem advisable. Allan Schenck was appointed to him by Mr. Peters. Mr. Schenk will report in the fall and make a recommendation for action.

TAPPI has decided that the TAPPI Data Sheets should be reviewed, reinvigorated, and reissued as Technical Information Sheets. Mr. Landers of TAPPI has undertaken this job. The Fourdrinier Committee was specifically asked to review Data Sheets Nos. 3, 3A, and 5. Data Sheet No. 5 was merely a basis weight, speed, width, production graph. It was moved, seconded, and carried to have the chairman conduct a letter ballot of the committee to withdraw Data Sheet No. 5. Consideration of Data Sheets Nos. 3 and 3A was postponed to next meeting. Mr. Hershey was assigned to examine the special report the TAPPI Committee put out on vacuum pump requirements to determine whether this could be the basis of a Technical Information Sheet.

The fall meeting of the Fourdrinier Committee will be held at 9:00 a.m., Sept. 29, 1961, at TAPPI Headquarters in New York City.

The meeting adjourned at 4.00 p.m. to allow the members to board a river boat for a delicious steak barbecue on the Oachita River. The following day, mill visits were arranged for the Olin-Mathieson mill in West Monroe, and the Crossett Paper Mills in Crossett, Ark.

RECENT BOOKS

Pipe Friction Manual. By The Hydraulic Institute, 122 E. 42nd St., New York 17, N. Y. Third Ed. Soft cover, $8^1/_2 \times 11$, 90 pages. $2.00 Domestic, $2.00 Foreign.

The material in this manual is an extension and rearrangement of the pipe friction data contained in the previous edition and in an earlier publication entitled, "Tentative Standards of the Hydraulic Institute—Pipe Friction."

These data are based on the latest information available. The form of the manual follows a pattern developed as the result of numerous suggestions from users of the earlier publications.

The manual features a section demonstrating the mathematical calculations used in the consideration of later charts. This is supplemented by complete tables of friction loss for water in feet per 100 ft. of pipe. Wrought iron, steel, and cast iron pipe sizes, from $^1/_8$ in. nominal to 84 in. i.d., are covered. Given also are tables of resistance coefficients for valves and fittings, 90° bends, diffusers, and others. The tables of resistance coefficients for valves and fittings include the latest available experimental data and show the values in more detail with respect to size and type than has heretofore been published.

The full page charts showing the friction loss for the incompressible flow of viscous fluids for pipe sizes from $^1/_2$ through 12 in. have been redrawn for greater clarity. Also included are three fold-in charts of friction factors with related data to permit the calculation of the friction loss for any fluid (liquid or gas) in any size or shape of conduit.

Of particular utility are numerous examples showing actual mathematical solutions to pipe friction problems. These have been checked and clarified to the point where the volume not only has become an essential tool for hydraulic engineers but it is also an excellent text of assistance to college instructors and students.

With the combination of formuli, friction loss moduli, friction factor charts, roughness factor charts, viscosity tables and associated information, the Pipe Friction Manual is a most complete and workable treatise on the subject. This edition features a very complete bibliography showing sources of data contained in the manual. It should fill a long-time need for a thorough and authoritative handbook on pipe friction.

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(P2019-61)

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537-61. Control Chemist desires position in laboratory of ink, varnish, paint, food, or plastic coatings plant.

538-61. Chemical Salesman presently employed. Technical sales to paper and converting industries. Mill background includes development, production, sales. Western location preferred.

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(P2015-61)

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TWO GRADUATE ENGINEERS

to serve as Technical Assistants to the Pulp and Paper Mill Superintendents.

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(P2018-61)

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(P2028-61)

ENGINEERING DIVISION

Project 792—Suction Box Covers

In the above report that appeared on page 153-A of the May issue of *Tappi* it is stated that the Union Carbide Corp. presented a new suction box cover material at the last meeting in February. H. Morton of the S. D. Warren Co., who is a member of this committee, has advised that this was an error and that this should have read that the Carborundum Co., Niagara Falls, N. Y., presented this new material.

Bibliography on Drying

The Drying Committee's chairman, F. G. Perry, Arthur D. Little, Inc., Cambridge, Mass., has compiled a selected bibliography on drying with J. A. Means, Time, Inc., Springdale, Conn., in charge of this committee activity.

The following bibliography is divided into nine categories and respective literature references are shown in each.

I. GENERAL THEORY

I—1. "Water Removal from Pulp and Paper," by T. K. Sherwood, H. S. Gardner, and R. P. Whitney, *Paper Trade J.* 106, No. 24: 29–35 (June 16, 1938).

I—2. "The Physics of Water Removal," by W. Boyd Campbell, *Pulp Paper Mag. Can.* 48, No. 3: 103–109, 122, Convention Issue (1947).

I—3. "The Mechanism of Hot-Surface Drying of Fibrous Sheets," by Arthur C. Dreshfield, *Chem. Eng. Progr.* 53, No. 174–180 (April, 1957).

I—4. "Mechanism of Drying of Pulp and Paper," by T. K. Sherwood, *Paper Trade J. T.S.* 134–136 (February, 1929).

I—5. "The Drying of Paper," by Arthur C. Dreshfield, Jr. and S. T. Han, *Tappi* 39, No. 7: 449–455 (1956).

I—6. "Lengthwise Elongation or Contraction and Shrinkage of the Paper Web in the Paper Machine," by Schumann, *Wochbl. Papierfabrik* 86, Nos. 23/24: 1033–1034, 1036 (December, 1958); *B.I.P.C.* 29, No. 8: 1177 (April, 1959).

I—7. "An Analytical Approach to the Problem of Drying of Thin Fibrous Sheets on Multicylinder Machines," by A. H. Nissan and W. G. Kaye, *Tappi* 38, No. 7: 385–398 (July, 1955).

I—8. "Heat Transfer in Hot-Surface Drying of Paper," by S. T. Han and Tapio Ulmanen, *Tappi* 41, No. 4: 185–189 (1958).

I—9. "The Effect of Drying and Heating on the Swelling of Cellulose Fibers and Paper Strength," by L. M. Lyne and W. Gallay, *Tappi* 33, No. 9: 429–435 (1950).

I—10. "Paper Drying Theory," by Mauri Soininen, *Paper Trade J.* pp. 36–40 (May 12, 1958).

I—11. "Introduction of Stress into a Paper Sheet During Drying," by Bertil W. Ivarsson, *Tappi* 37, No. 12: 634–639 (1954).

I—12. "Effect of Water Removal on Sheet Properties," by Herbert F. Rance, *Tappi* 37, No. 12: 640–654 (1954).

I—13. "Some Factors Affecting Drying in Paper Machines," by H. Preston-Thomas and T. M. Dauphinee, *Pulp Paper Mag. Can.* 159–164 (April, 1957).

I—14. "Uniformity of Drying Across a Sheet," by H. Preston-Thomas, *Pulp Paper Mag. Can.* 73–76 (February, 1958).

I—15. Cross-Directional Uniformity of Drying on a Paper Machine," by John Verwayen, *Tappi* 41, No. 9: 160A–162A (September, 1958).

I—16. "Performance Testing the Dryer Section of a Paper Machine," by G. J. Chalmers, *Pulp Paper Mag. Can.* 236–243, 273 Convention, (1954).

I—17. "Drying of Paper on the Machine," by B. M. Baxter, Fritz Publications, Inc., Chicago.

I—18. "Recent Studies of Paper Drying," by H. Preston-Thomas, *Pulp Paper Mag. Can.* T17–T20 (January, 1959).

I—19. "Paperboard Drying Investigation by Means of an Experimental Drying Machine," by S. F. Smith and B. W. Attwood, *Tappi* 36, No. 11: 481–490 (November, 1953).

I—20. "Drying Theory and Practice," by C. E. Hill and C. J. Pyle, University of Maine Lecture, Series II, pp. 308–323.

I—21. "Heat Transfer Calculations for Paper Machines," by A. E. Montgomery, *Tech. Assoc., Papers* 29: 525–528 (1946).

I—22. "Knowledge and Its Enlargement, *British Paper Maker* 102–105 (February, 1954).

I—23. "High Frequency Heating," by R. R. Baker and C. J. Madsen, *Tech. Assoc. Papers* 27: 160–165 (1944).

I—24. "A Theory of Paper Drying," by E. Cowan and B. Cowan, *Tech. Assoc. Papers* 20: 271–277 (1937).

I—25. "The Effect of Hydration Upon the Rate of Drying of Paper Sheets," by J. G. L. Caulfield, L. C. Jenness, and H. G. Macklem, *Tech. Assoc. Papers* 22: 309–312 (1939).

I—26. "Effects of the Principal Variables on the Rate of Air Drying," by D. W. McReady, *Tech. Assoc. Papers* 19: 393–396 (1936).

I—27. "Mechanism of Drying of Pulp Slabs on Heated Surfaces," by D. W. McReady, *Tech. Assoc. Papers* 19: 396–401 (1936).

I—28. "Drying of Paper in the Papermaking Process," by A. E. Montgomery, Boston, William L. Barrell Co., 1954, 43 pages, Library TS 1109.

II. DRUM DRIERS

II—1. "Factors Affecting Dryer Performance," by R. J. Chambers, *Pulp Paper Mag. Can.* 154–162, Convention (1937).

II—2. "Drying of Paper on Felt-Covered Rollers," by S. Ponton, *Svensk Pappers Tidning* 62, No. 19 (Oct. 15, 1959).

II—3. "The Role of Woolen Felts in the Removal of Water in the Dryer Section of a Paper Machine," by J. R. Bell, W. F. E. Robinson, and A. H. Nissan, *Tappi* 40, No. 7: 558–564 (1957).

II—4. "The Drying of Paper on Felt-Covered Cylinders; The Importance of the Felt as Regards the Transport of Heat and Moisture," by O. Brauns and S. Ponton, *Svenske Pappers Tidning* (April 15, 1959).

II—5. "A Theory of Drying of Sheet Materials, by Using Heated Cylinders," A. H. Nissan, *Chem. & Ind.* 198–211 (April 7, 1956).

II—6. "Drying of Paper on Felt-Covered Cylinders," by L. Janson and B. Nordgren, *Svensk Pappers Tidning* (Oct. 15, 1958).

II—7. Discussion—*Tappi* 32, No. 1: 52A, 54A, 56A (1949).

II—8. "Newsprint Drying Questionnaire Summary," by E. H. Snider, *Pulp Paper Mag. Can.* 254–261, Convention (1957).

II—9. "Trouble Shooting in the Dryer Section," by C. J. Lyons, *Pulp Paper Mag. Can.* 262–265, Convention, 1957.

II—10. "Drying Rates of Newsprint—1942," by W. G. MacNaughton, *Tech. Assoc. Papers* 26: 217–223 (1943).

II—11. "Drying Rate for Kraft Paper," by A. E. Montgomery, *Tech. Assoc. Papers* 25: 511–514 (1942).

II—12. Dryer Section Arrangement for Paper Machines, U. S. pat. 2,909,847.

II—13. "Evaluation of Drier Performance," by F. W. Adams and A. E. Montgomery, *Tech. Assoc. Papers* 19: 323–325 (1936).

III. YANKEE DRIERS

III—1. "General Factors Concerning MG Machine Operation," by J. Chapman, *Pro. Tech. Sect. Brit. Paper and Board Makers Assoc.* 1, No. 1: 33–40 (February, 1960).

III—2. "Observations on Drying on Yankee Type Cylinders," M. Knowles, J. Mardon, and R. White, *Pro. Tech. Sect. Brit. Paper and Board Makers Assoc.* 36, Part 1, 1955.

III—3. "Heat Transmission in the Drying of Paper on a Yankee Cylinder," by O. Brauns and A. L. Jansson, *Svensk Pappers Tidning* 60, No. 17: 621–631 (Sept. 15, 1957).

III—4. "Determining the Capacity of Yankee Cylinders," by L. Janson, *Svensk Pappers Tidning* (Oct. 15, 1957).

III—5. "The Diameter and the Steam Pressure of a Yankee Cylinder," by Karl Boll and Helgy O. Wahlberg, *Svensk Pappers Tidning* 58, No. 18 (Sept. 30, 1955).

III—6. "The M. G. Machine," by F. A. Craig, *Paper and Print* 24, No. 4: 420, 2, 4, 6, Winter, 1951.

III—7. "Operating Experiences with the Yankee Machine of the Kuusankoski Paper Mill, After Fitting Suction Couch and Presses," by L. Sundstrom, *Paper and Timber* (Finland), 1953, 35, No. 8: 314–318 (1953).

III—8. "Some Aspects of Heat Transfer During Yankee Drying," by Herminge and L. Janson, *Svensk Pappers Tidning* 63, No. 2: 15–23 (Jan. 31, 1960).

III—9. Paper Machine Dryer, U. S. pat. 2,892,263.

III—10. "The Function of a Yankee Drier on a Paper Machine," by Kurt Wandel, *Tech. Assoc. Papers* 25: 229–234 and 81–83 (1942).
III—11. "The Operation of an Air Recirculation System for M. G. Hood Drying," by J. Chapman, *Pulp Paper Mag. Can.* 102–106 (June, 1950).
III—12. Paper Machine Dryer Assembly U. S. pat. 2,784,652.

IV. AIR IN DRYING

IV—1. "An Analysis of Air-Impingement Drying," by R. A. Daane and S. T. Han, 15th TAPPI Engineering Conference.
IV—2. "The Influence of Air on Drying," by A. E. Montgomery, *Paper Trade J.* 30–31 (June 3, 1937).
IV—3. "Tons of Air for Drying Paper," by L. G. Janett, *Paper Trade J.* 16–18 (Dec. 22, 1938).
IV—4. "Air Impingement Drying," by Claes Allander, 15th TAPPI Engineering Conference.
IV—5. "Study of the Grewin System," by R. J. Chambers, *Pulp Paper Mag. Can.* 88–90 Convention (1938).
IV—6. "High Velocity Air Drying on Yankee Machines," by J. Chapman, *Svensk Pappers Tidning* 321–326 (May, 1952).
IV—7. "High Velocity Drying of Clay-Coated Papers," by M. H. Vander Velde, *Tappi* 42, No. 11: 155A–157A (1959).
IV—8. "The Skin-Drying Effect in Hot Air Drying of Paper and Board," by A. P. Arlov, *Norsk Skogindustri* 174–182 (May, 1958).
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RC 300. Racking Strength of Structural Insulating Board

This method is derived from racking test Method B of ASTM E 72–55. The method is specified here for structural insulating board but is applicable to other types of sheet or plank materials as well.

This method of test measures the resistance of panels, having a standard wood frame and sheathed with structural insulating board, to a racking load such as would be imposed by winds blowing on a wall oriented at 90° to the panel. It is intended to make available a reliable, uniform procedure for determining the resistance to racking load provided by the board. Since a standard frame is employed, the relative performance of the board is the test objective.

The test is conducted with standardized framing, loading procedures, and method of measuring deflection, to insure reproducibility. Provision is made for following the manufacturers recommendations for attaching the board to the frame and for reporting the behavior of the specimen over its entire range of use.

In applying the results, due allowance shall be made for any variation in construction details or test conditions from those in actual service.

Apparatus

The method described is specifically applicable to tests conducted in a testing machine but other adequate means of load application may also be used. A maximum load capacity of 10,000 lb. is generally adequate. Load shall be measured by means of the testing machine or a dynamometer attached to cables that load the specimen or in linkage with a hydraulic jack used to apply load. The essential parts of the testing apparatus, exclusive of the testing machine or loading frame, are as follows:

1. Base and Attachment of Specimen to Lower Platen of Testing Machine or Frame—The test panel shall be attached to a timber or steel plate that is in turn attached rigidly to the base of the testing machine or loading frame. This member may be of any convenient cross section, but it shall be at least as long as the panel. Means shall be provided to bolt or otherwise attach the sole plate of the panel firmly to this member. For illustrative purposes, two bolts are shown in Fig. 1. More may be used if required.

2. Hold-Down—A hold-down shall be provided as shown in Fig. 1 to overcome the tendency of one end of the panel to rise as the racking load is applied. Plates and rollers shall be provided between the test specimen and the hold-down so that the top of the specimen can deflect horizontally with respect to the bottom without unnecessary interference from the hold-down. Because the amount of tension in the rods of the hold-down may have an effect on the results of the test, nuts on the hold-down rods shall be tightened so that the total force in each rod does not exceed 20 lb. at the beginning of test as determined by previous calibration.

3. Load-Applying Apparatus—Load shall be applied to the specimen through a 4 by 6-in. timber firmly bolted to the upper plates of the panel as shown in Fig. 1. Loading shall be compressive force against the end of the timber attached to the upper plate. When a testing machine is used, pulleys and cables such as shown may be used to transmit the vertical movement of the tension head of the machine to the horizontal movement in the specimen.

4. Lateral Guides—Lateral guides, such as shown, shall be provided so that the specimen will deflect in a plane. The rollers should be bearing-supported to reduce friction to a minimum. The lateral guides shall be firmly attached to the frame of the testing machine or to a frame attached to its base. Plates for the rollers may be up to 12 in. in length as required.

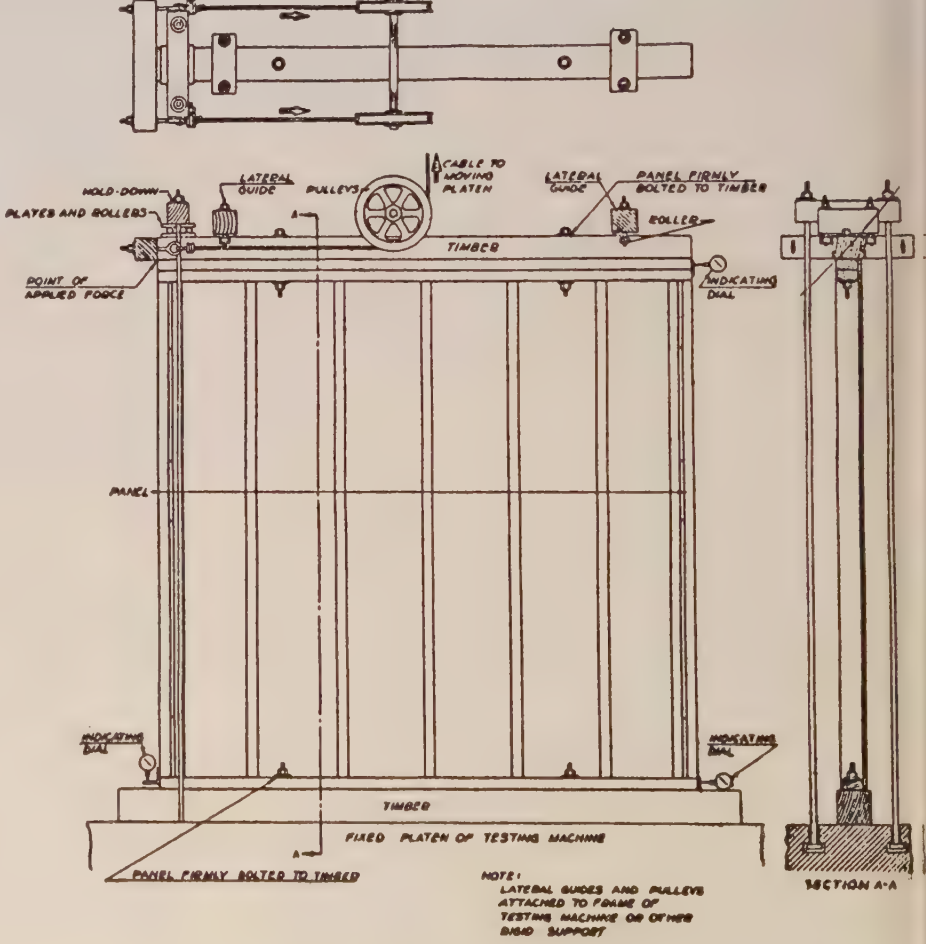


Fig. 1. Racking load assembly

5. Indicating Dials—Indicating dials, or scales and wires, shall be provided to measure the displacement of the different parts of the panel during test. The readings shall be accurate to the nearest 0.01 in. The locations of the dials shall be as shown in the lower left, lower right, and upper right corners of the side view of the test assembly in Fig. 1. The dial at the lower left, which is attached to the stud, measures any rotation of the panel, the dial at the lower right measures any slippage of the panel, and the dial at the upper right measures the total of the other two plus the deformation of the panel. Therefore, the horizontal deflection of the panel at any load is the reading of the dial at the upper right less the sum of the readings of the other two.

Note: Dial gages reading 0.001 in. and having total travel of 4 in. or more are available.

Test Specimens

1. The test specimen shall be 8 by 8 ft. and the framing shall be constructed as shown in Fig. 2. It is the intent of this test procedure to evaluate the stiffening effect of the sheathing material; therefore, the frame shall be constructed as nearly like the frames shown in Fig. 2 as possible. Frames shall be newly constructed for each test. All individual framing members shall be continuous. The moisture content of framing material shall be between 12 and 15% when the panel is fabricated.

2. The method of applying the sheating shall be exactly as specified by the manufacturer. The spacing of nails shall be as recommended. Nails shall be driven through the sheathing into only the outside 2 by 4-in. timber of each corner post shown in Fig. 2. The importance of the nailing of sheathing to the framing cannot be overemphasized. Slight differences in edge clearances, angle of nail, and amounts of penetration of heads of nails into the sheathing have appreciable effects on the results of test. Nails shall be driven perpendicular to the surface of the sheathing with the center of each nail the specified distance from the edge of the sheathing. Nails shall be driven so that the head of the nail contacts the surface of the sheathing but not so deep as to crush the surface.

Conditioning of Specimens

1. Unless otherwise required, the specimens shall be tested in the normal moisture condition.

2. Where it is desired to simulate the degree of wetting possible during construction of a structure when, because of rain, the framing and sheathing may be wetted one one or both sides, the following procedure is recommended. Both sides of the wall panel are wetted because this represents the maximum exposure possible during the stage of construction before the structure is roofed.

Conditioning

The fabricated test specimens shall be mounted or suspended in a vertical position in such a manner as to prevent continuous immersion of the bottom edge of the specimen. Both sides of the test specimen shall be exposed to a water spray applied at or near the top along the entire length to insure that the top of the specimen is being wetted. The spray shall have no jet action that cuts into the sheathing material, and the spray areas shall overlap sufficiently so that a continuous sheet of water flows down both surfaces of the specimen. The temperature of the water in the line to the spray nozzle shall be maintained at 75 ± 5°F. The specimens shall be wetted for a period of 6 hr. and then allowed to dry for a period of 18 hr. The drying shall take place in laboratory air, preferably at a temperature of 75 ± 5°F. No attempt shall be made to increase the air movement over the specimens by fans or blowers. The test specimens shall be subjected to two complete wetting and drying cycles and then a third wetting cycle. The racking test shall commence within 2 hr. after the completion of the third wetting cycle.

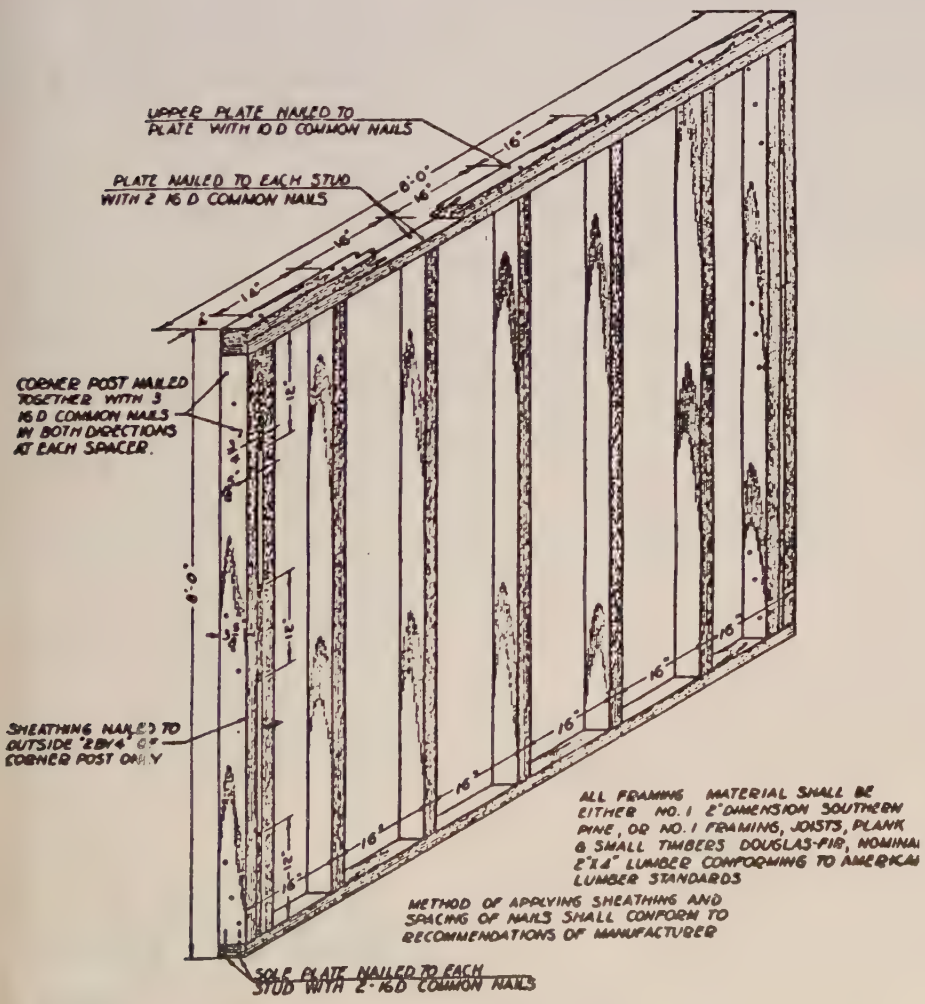

UPPER PLATE NAILED TO PLATE WITH 10D COMMON NAILS
PLATE NAILED TO EACH STUD WITH 2 16D COMMON NAILS
CORNER POST NAILED TOGETHER WITH 3 16D COMMON NAILS IN BOTH DIRECTIONS AT EACH SPACER.
SHEATHING NAILED TO OUTSIDE 2 BY 4" OF CORNER POST ONLY
ALL FRAMING MATERIAL SHALL BE EITHER NO. 1 2" DIMENSION SOUTHERN PINE, OR NO. 1 FRAMING, JOISTS, PLANK & SMALL TIMBERS DOUGLAS-FIR, NOMINAL 2"14" LUMBER CONFORMING TO AMERICAN LUMBER STANDARDS
METHOD OF APPLYING SHEATHING AND SPACING OF NAILS SHALL CONFORM TO RECOMMENDATIONS OF MANUFACTURER
SOLE PLATE NAILED TO EACH STUD WITH 2-16D COMMON NAILS
8'-0"
16"

Fig. 2. Test panel specimen

Procedure

1. Loading—The load shall be applied continuously throughout test at a uniform rate of motion of the movable platen of the testing machine or other loading device used. The recommended speed of testing shall be such that the loading to 800 lb. total load shall be completed in not less than 2 min. from the start of test (Note 1). The loading to 1600 and 2400 lb. total load to failure shall employ the same rate of travel of the platen of loading device as for the loading to 800 lb. The speed of testing used shall be given in the report of test.

Note 1: It is not possible to present a single testing speed because of the variations in the relative rigidity of the various types of panels that can be used.

2. Loading Procedure—The specimen shall be loaded in three stages to 800, 1600, and 2400 lb. total load at a uniform rate (Note 2). After the load of 800 lb. is placed on the specimen, all of the load shall be removed and any residual deflection (set) in the panel noted. The specimen shall then be loaded to 1600 lb. and the load again removed and any additional set noted: after which the loading shall be increased to 2400 lb. and the load again removed and the set again noted. Load shall be applied continuously for each of the increment loads specified above and load-deflection data obtained. These data should be obtained for at least each 200 lb. of loading. Deflections should be obtained during the loading cycle, and if desired during the unloading cycle as well.

After the specimen is loaded to 800, 1600, and 2400 lb., it shall be loaded again to failure or until the total deflection of the panel becomes 4 in. (Note 3). Readings of deflection should be obtained for the same intervals of load as were used for the other loadings.

Note 2: To provide data to meet performance requirements, other values of total load may be included in the test procedure. The same rate of loading should be used as for the loadings specified and the report shall indicate additional loadings evaluated and the results obtained.

Note 3: Some constructions will continue to deflect under increasing load with no apparent maximum load, but the deflections will become so great that any data obtained from extending the test would be of little importance.

3. Sampling of Sheating—Immediately after the racking test is completed, five samples at least 6 by 6 in. in size shall be taken from each 4 by 8 ft. sheathing panel of the test specimen. One sample shall be taken from the center of each panel at the top and bottom edges, one from midlength on each side and one from the panel center.

4. Determination of Moisture Content—The samples shall be weighed immediately after being cut from the test panels to an accuracy of not less than ±0.2%. All loose particles shall be carefully removed from the sample before weighing. The samples shall then be dried to constant weight in an oven at 220 ± 5°F. The samples shall again be weighed and the moisture content calculated as follows:

$$M_w = 100\,\frac{(W - F)}{(F)}$$

where

M_w = moisture content in per cent by weight
W = initial weight, grams
F = final weight, grams

$$M_v = \frac{6.1\,(W - F)}{l \times b \times d}$$

where

M_v = moisture content in per cent by volume
l = length, inches
b = width, inches
d = thickness, inches

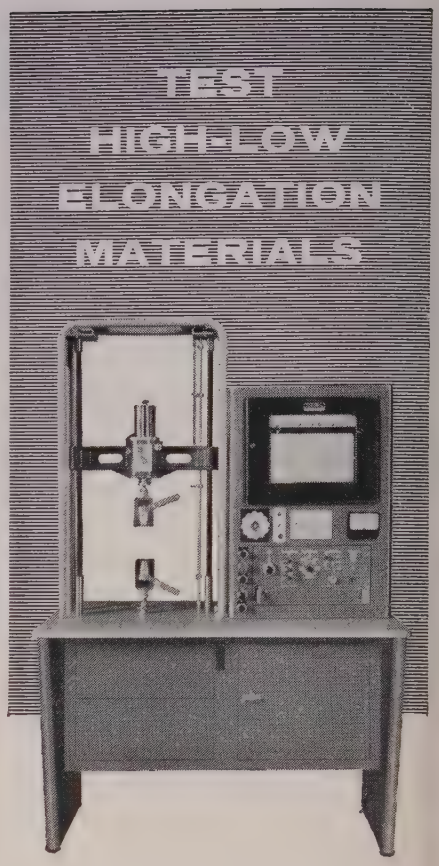
Calculation of Report

1. For each dial, or other measuring device, the movement under each racking load shall be calculated as the difference between the readings when load is applied and the initial readings at the start of the test. Set readings shall be calculated as the difference between the readings when the load is removed and the initial readings.

2. The report shall indicate the deflections at 800, 1600, and 2400 lb. and the set after loading to these amounts. Load-deflection curves obtained during loading to failure and to 800, 1600, and 2400 lb. shall be presented in the form of a graph. Maximum load and any observations on the behavior of the panel during test and at failure shall be included. Residual deflections (sets) shall be expressed as percentages of the deflections that produced the sets as well as in inches.

If the specimen fails, the visible failure shall be described. If the specimen has been subjected to any special conditioning prior to test, this treatment shall be described in detail. The report shall describe the sheathing used, the method of applying the sheathing, the type and spacing of nails, and the method and rate of loading employed. It is also desirable to report thickness, dry density, and moisture content expressed by both weight and by volume.

This method was prepared and recommended by the Structural Fibrous Materials Committee of the Paper and Board Manufacture Division.



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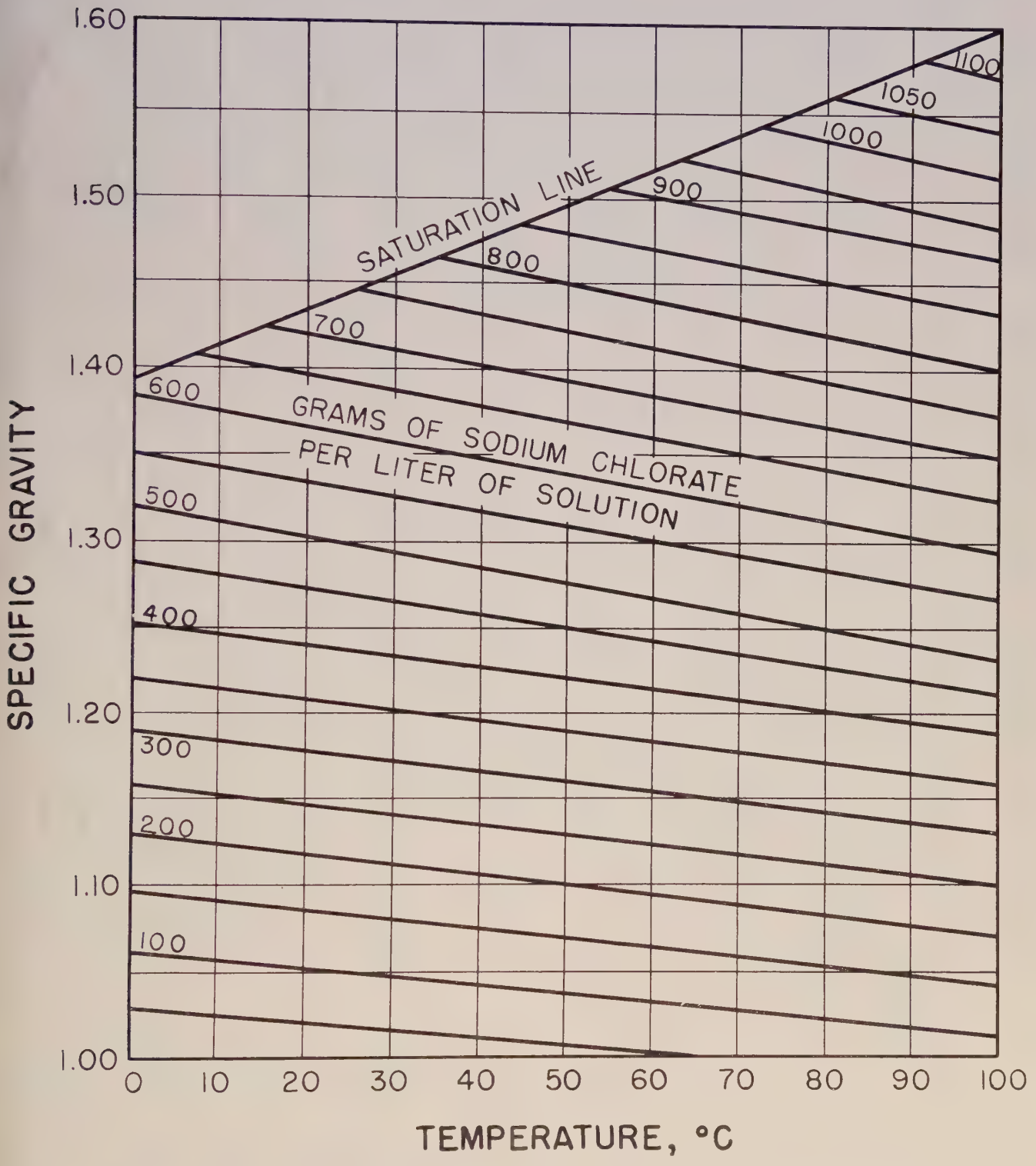
Specific Gravity of Sodium Chlorate Solutions

Technical Information Sheet No. 1

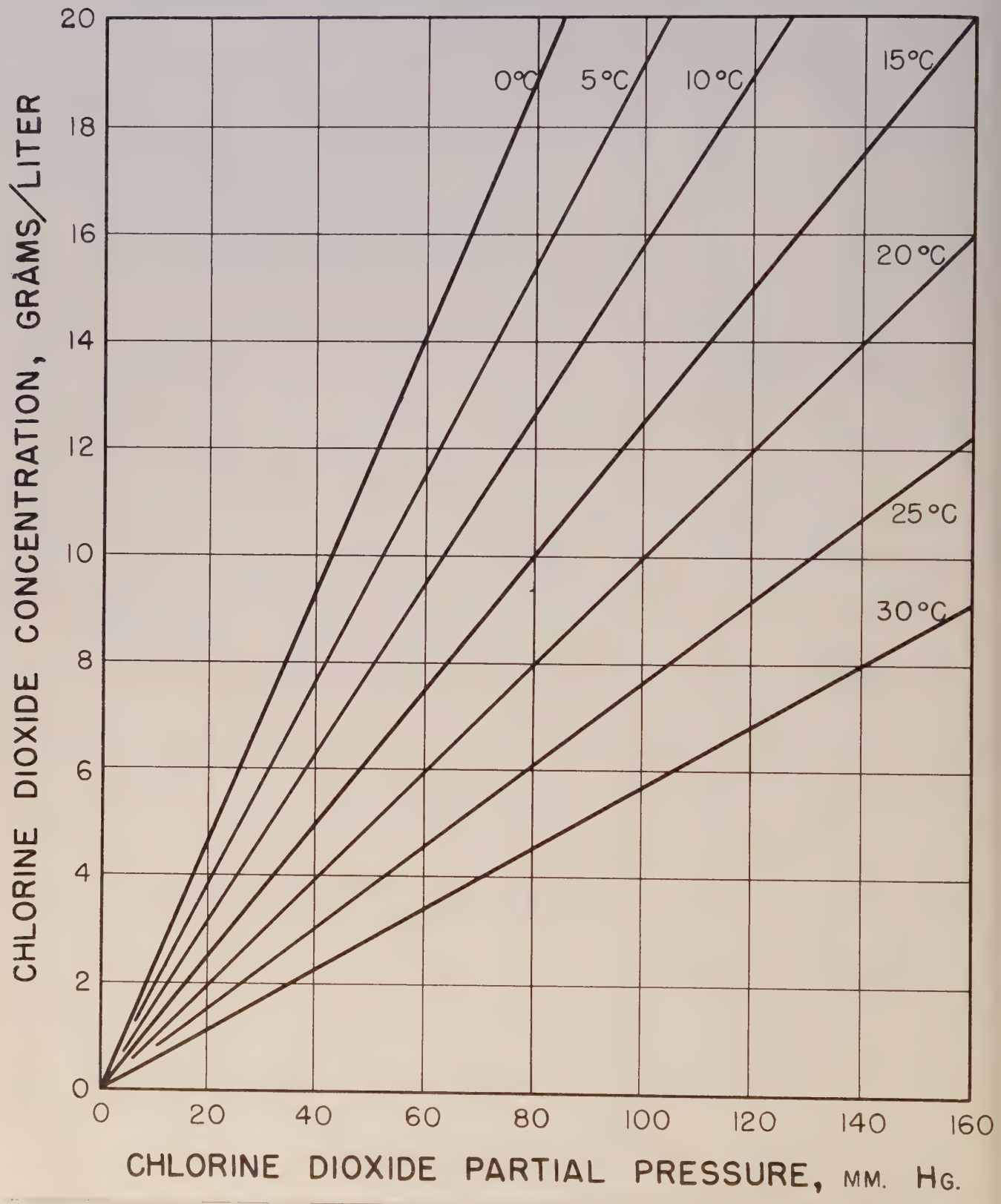


Prepared by: Chemical Engineering Committee (C.A. 4003).

Source: Hooker Chemical Corp., Niagara Falls, N. Y.

Equilibrium Solubility of Chlorine Dioxide in Water

Technical Information Sheet No. 2



Prepared by: Chemical Engineering Committee (C.A. 4004).

Source: Haller, J. F. and Northgraves, W. W., *Tappi* 38, No. 4: 199, (Apr., 1955).

LOCAL SECTION ACTIVITIES

Local Section Meetings

September, 1961

11	Bay District, New England Section, Armands Beacon Terrace, Framingham, Mass.
12	Metropolitan District, Empire State Section, Stouffers, 100 E. 42nd St., New York, N. Y.
12	Ohio Section, Manchester Hotel, Middletown, Ohio.
15	Gulf Coast Section, Cover Hotel, Panama City, Fla.
18–19	Pacific Section, Portland State College, Portland, Ore. Annual Seminar, Alfred Stamm, lecturer.
21–22	Pacific Section, University of Washington, Seattle, Wash. Annual Seminar, repeated.
19	Indiana District, Ohio Section, Marott Hotel, Indianapolis, Ind.
21	St. Louis Section, Stratford Hotel, Alton, Ill. Visit to mill of Alton Box Board Co.
22	Southeastern, Robert Meyer Hotel, Jacksonville, Fla.

October, 1961

3	Chicago Section, Chicago Bar Association, 29 S. LaSalle St., Chicago, Ill.
4	Western District, Empire State Section, Apple Grove Inn, Medina, N. Y. Visit to mill of United States Gypsum Co., Oakfield, N. Y.
6–7	Pioneer Valley District, New England Section, Equinox House, Manchester in the Mountains, Vt. Joint meeting with PIMA Connecticut Valley Division.
10	Metropolitan District, Empire State Section, Stouffers, 100 E. 42nd St., New York, N. Y.
12	Ohio Section, Chillicothe, Ohio. Visit to the laboratories of Mead Corp.
17	Indiana District, Ohio Section, Terre Haute, Ind. Visit to mill of Weston Paper and Manufacturing Co.
20–21	Maine-New Hampshire Section, Mountain View Inn, Whitefield, N. H.

Note: Chairmen and Secretaries of local sections are urged to advise the Association headquarters office about dates and locations of future meetings and to indicate any errors in the calender of meetings as presented. Write to R. G. Macdonald, Editorial Director of *Tappi*, 360 Lexington Ave., New York 17, N. Y.

Southeastern

The last meeting of the year for the Southeastern Section of TAPPI was held May 19–20 at the General Oglethorpe Hotel in Savannah, Ga. This meeting included a technical program, election of officers, and a social program for section members and their wives.

The group attending the meeting was greeted by J. R. Lientz, vice-president of Union Bag-Camp Paper Corp. P. E. Nethercut of National TAPPI Headquarters also spoke.

G. C. Kimple, chairman of the section's Nominating Committee, submitted the following slate of candidates for office:

R. A. Flick, Brunswick Pulp and Paper Co., chairman
B. M. Reaves, Sonoco Products Co., vice-chairman
Julian Daniel, Union Bag-Camp Paper Corp., treasurer
James H. Smith, Continental Can Co., recording secretary

The officers were unanimously elected.

The evening program included technical discussions for the men with bingo and bridge for the ladies.

The feature speaker for the meeting was John W. Swanson of The Institute of Paper Chemistry. His topic was "Foam in Paper Stock."

In the presentation, Mr. Swanson described some of the conditions required for foam to take place, the mechanism of foaming, and some of the requirements for antifoam materials.

The last part of the program was made up of a panel discussion on "Hot Stock Screening." Panel members included:

Ralph C. Hall, Union Bag-Camp Paper Corp.
Albert L. Conner, Rome Kraft
Michael J. Dunford, Continental Can Co.
Robert W. Stoertz, West Virginia Pulp and Paper Co.

Each panel member described his own screening system and the benefits gained. A discussion by the group followed.

On Saturday morning, the program included bridge, golf, fishing, and a tour of Savannah. These events were followed by a luncheon and the awarding of prizes for golf and fishing.

M. Benjamin, *Recording Secretary*

Maine-New Hampshire

Mill Application of Hydrosulfites for Bleaching Groundwood Pulp

R. W. Barton

In the application of hydrosulfite for the bleaching of groundwood, the chemical should be mixed thoroughly with the pulp with a minimum amount of air exposure. Mixing should be fast enough to give complete distribution of the bleaching chemical throughout the pulp in less than 4 min. Once the hydrosulfite and pulp have been blended together, protection of the stock from atmospheric oxygen should be continued until completion of the desired retention period. The best equipment arrangement which will allow zinc hydrosulfite to be applied under these conditions includes a stock heater, a vessel where entrained air can be purged, a system for mixing which allows a solution of the bleaching chemical to be distributed rapidly into the pulp well below the air-stock interface and a retention vessel in which air is excluded from the stock. When these provisions have been made, the full economy of the hydrosulfite bleaching process can be realized. Costs as low as 25 cents per ton per point of brightness increase and gains up to 12 points can be obtained with spruce groundwoods.

Early experience with hydrosulfites in the paper industry was limited almost entirely to applications in which the desired brightness improvement was less than 5 points. Expansion of the end-use for mechanical pulps into the printing grade field led to renewed interest in hydrosulfites for bleaching. A number of improvements in conditions and methods of application were made. The use of heat to drive the reaction (*1*), the application of sequestering agents, such as sodium tripolyphosphate and ethylenediaminetetraacetic acid as brightness stabilizers (*2*), and improvements in the

R. W. Barton, Supervisor, Technical Service Dept., Research and Development, Virginia Chemical & Smelting Co., West Norfolk, Va.

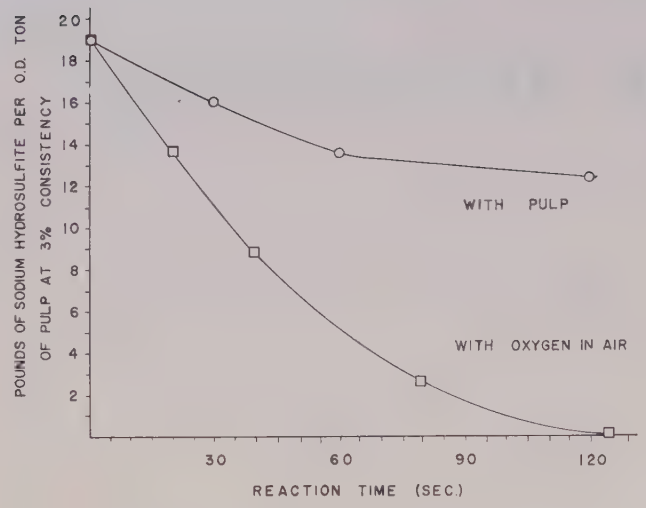


Fig. 1. Reaction rates of sodium hydrosulfite with pulp and oxygen

The upper curve gives measured concentrations of sodium hydrosulfite (100%) in a 3.0% O.D. consistency slurry treated at 130°F. in an air-free system. The lower curve was calculated from the equation $K_C = 6.8 \times 10^{-4} = 2/\theta(C_0^{0.5} - C^{0.5})$, where θ = time in seconds, C_0 = initial concentration in gram moles per liter, and C = concentration at time θ. The constant for 130°F. was extrapolated from values given by Rinker, *et al.* (*6*).

techniques of applying the bleaching chemical to the pulp (*2–5*) resulted in a process which will yield 12 points of brightness increase with spruce groundwood.

Of the improvements made in the hydrosulfite process, the physical methods of treating the pulp have proved to be the most important in achieving high brightness. The object of this paper is to review the technique of application and to show what steps can be taken to get not only the highest brightness values, but the best efficiency when brightness increases of 4 to 9 points are desired. The discussion will be limited to the basic requirements of application and to the equipment arrangements with which these requirements can be met.

The techniques of hydrosulfite application are based almost entirely upon consideration of the extreme reactivity between dissolved hydrosulfite and oxygen. Of some additional importance is the decomposition of dissolved hydrosulfite by auto-oxidation reduction. Equations for both of these two reactions which compete with the pulp for the bleaching chemical are as follows:

$$Na_2S_2O_4 + O_2 + H_2O = NaHSO_3 + NaHSO_4 \qquad (1)$$

$$2Na_2S_2O_4 + H_2O = Na_2S_2O_3 + 2NaHSO_3 \qquad (2)$$

The reaction of oxygen with dissolved hydrosulfite is quite fast. In mill application, it can be assumed to be restricted only by the rate of diffusion of oxygen from the air into the solution or pulp slurry containing the hydrosulfite. A comparison of the reaction rates of sodium hydrosulfite with the oxygen in air and with groundwood pulp is shown in Fig. 1. The upper curve gives the disappearance of hydrosulfite in air-free, spruce groundwood slurry of 3.0% consistency at 130°F. These values were obtained by measuring the residual present with a standard azo rubine dye solution. The lower curve shows the calculated rate of oxidation based upon reaction constants given by Robert J. Rinker (*6*) following a study of the oxidation of the hydrosulfite ion in solution. The ordinate is given in pounds of hydrosulfite per ton of oven-dry stock* in the slurry. The abscissas is in seconds. From these curves, if diffusion is not controlling—that is, if agitation is sufficient to replace the oxygen in solution as fast as it reacts with the hydrosulfite, the amount of chemical added in a 1% bleach (94% sodium hydrosulfite) at 3% consistency is consumed by atmospheric oxygen in 125 sec. In this same interval, about 30% of the chemical is used in the bleaching reaction. Of vital importance for efficient hydrosulfite bleaching, then, is the prevention of the competing, oxygen-hydrosulfite reaction by exlcuding all possible air from the stock, and also by avoiding conditions which would encourage diffusion of atmospheric oxygen into the treated pulp.

The auto-oxidation-reduction reaction (equation (2)) is catalyzed by acidity. In soultion, this reaction takes place rapidly below pH 5 and practically instantaneously below pH 4.2. Oxidation of hydrosulfite by either air or pulp raises the hydrogen ion concentration which in turn accelerates the auto-oxidation-reduction. Measures taken to exclude air from the pulp also retard the rate of the second competitive reaction. In the absence of air, the amount of hydrosulfite lost to auto-oxidation-reduction can be minimized by exposing the chemical as quickly as possible to unreduced pulp. Laboratory tests have indicated that distribution of the chemical throughout the stock should be completed within 4 min. This is the second major factor which must be recognized when using hydrosulfites.

Applying these two considerations to the steps in the hydrosulfite bleaching process—which consists of heating the stock, blending in the bleaching chemical, and then holding the treated pulp until the brightness ceases to increase—results in the following rules for effectively using hydrosulfites:

1. All possible air should be removed from the stock before the addition of the bleaching chemical. If steam is used, provisions should be made to allow air liberated from the pulp by the temperature increase to escape.
2. The chemical should be rapidly and thoroughly mixed with the stock in the absence of air.
3. The stock should not be exposed to air until the desired holding time has expired.

The significance of these rules is illustrated by the data presented in Fig. 2. These are laboratory results taken under

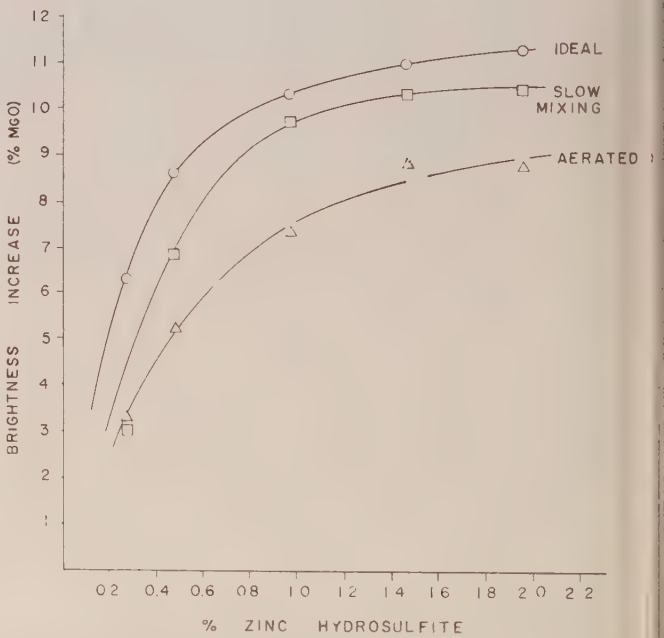


Fig. 2. Effect of mixing conditions on brightness increase

All bleaching tests were carried out for 2.0 hours at 3.3% consistency and at 130°F. using 0.20% sodium tripolyphosphate as an auxiliary agent. Hand-sheets were formed from 0.5% consistency slurries of pH 4.5 adjusted with sulfuric acid. Data for the upper two curves were taken using a nitrogen blanketed system. For the second curve, the hydrosulfite was added to one-half of the pulp and mixing was completed after four minutes. For the lower curve, air at a controlled rate was injected into the stock for one minute prior to, during, and one minute following the mixing step. The samples were exposed to the atmosphere during the retention period.

* All consistencies and reagent concentrations given in this paper are based on the ovendry weight of the pulp.

several conditions of mixing and retention. In all cases, groundwood pulp made from essentially sprucewood was bleached for 2 hr. at 130°F. at 3.3% consistency with varying of zinc hydrosulfite. The top curve illustrates ideal mixing and retention conditions, i.e., practically all of the air was removed from the stock, mixing was nearly instantaneous, and retention was air free. The second curve shows what happened when zinc hydrosulfite was added to approximately one-half of the pulp which was allowed to stand for 4 min. and then mixed with the untreated stock. The stock was then retained until the total elapsed time between the initial chemical addition and the end of the bleach was 2 hr. The lower curve shows what happened when air was injected into the pulp during the mixing step and when no attempt was made to protect the sample from further oxidation by air during the retention period.

When either mixing was retarded or air was not excluded during the mixing and retention steps, the maximum possible brightness was decreased and the amount of zinc hydrosulfite required to reach all levels of brightness was raised. The following table gives the brightness values obtained under each condition of mixing with 1.0% zinc hydrosulfite, the quantity of zinc hydrosulfite required for an 8-point increase, and the cost penalty incurred by deviating from the ideal at the 8-point level.

Mixing condition	*Brightness increase with 1.0% ZnS_2O_4, % MgO*	*ZnS_2O_4 for 8 points of increase, lb./ton*	*Cost of additional chemical for 8 points, $/ton*[a]
Ideal	10.5	8	0
Slow	9.7	12	0.86
Aerated	7.8	24	3.44

[a]Based on 21.5 cents per lb. for zinc hydrosulfite.

It should be emphasized that the data presented in Fig. 2 are empirical and serve only to illustrate what can happen when the rules for bleaching are violated. In plant scale operations, variations in conditions can be either more or less extreme than those used in the laboratory and changes in brightness and efficiency can be either a more or less critical problem.

In showing how the rules for using hydrosulfite are applied in plant operation and design, examples of tower and chest bleaching systems will be used. The examples are all low density unit which are the most common type. Several medium-density plants have been constructed and operated for both single-stage treatment and for bleaching in combination with peroxides. Medium density bleaching requires special and unique equipment, however, and descriptions of these units have not been included in this paper.

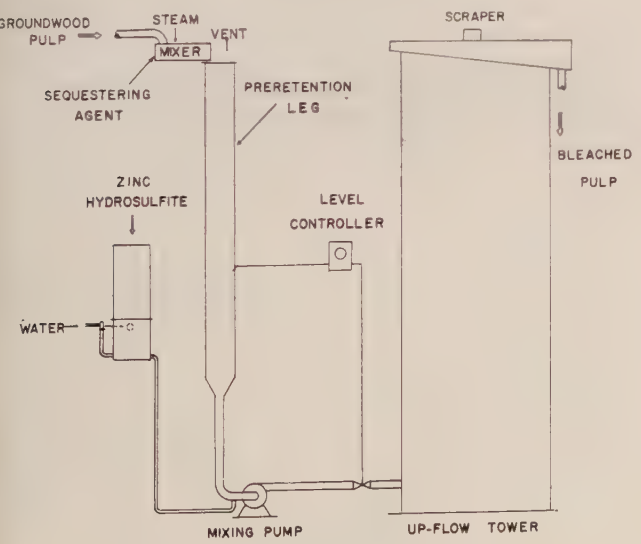


Fig. 3. Tower bleaching system

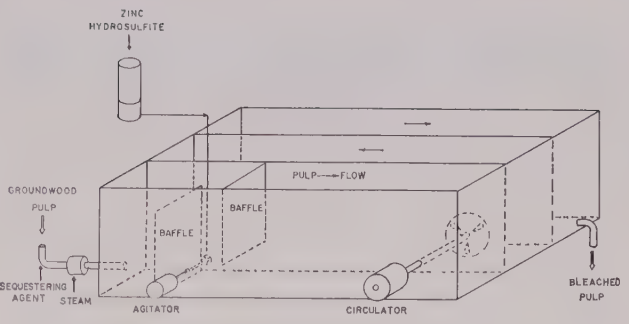


Fig. 4. Chest bleaching system

An example of a low-density bleach plant in which the rules for using hydrosulfites are observed is given in Fig. 3. Stock of regulated consistency is metered into a steam mixer where the temperature is raised to the desired value with live steam. The pulp then falls into a preretention leg in which the level is automatically regulated and passes through a pump which serves as a mixer and simultaneously impels the pulp up through the bleaching tower. At the completion of the retention period, the bleached stock is scraped into a launder ring and is transferred to storage. Liquor is prepared as required with a dry feeder-dissolving basin arrangement and is injected into the stock ahead of the mixing pump. If a sequestering agent is used, it is added in the steam mixer as a solution.

Each of the rules for good bleaching are observed in this plant. Several provisions are included to assure air-free operation. One is centered on the preretention leg, an expanded section of pipe where the linear velocity of the stock is lowered to 5 f.p.m. At this velocity, air entrained in the steam mixer and air liberated by the increase in stock temperature can escape from the pulp. Automatic control of the stock level in the leg gurantees that the mixing pump will always operate with a flooded suction. The whole mixing section of the unit is under a positive pressure which prevents air leakage into the system through the fittings and valves. Rapid and thorough distribution of the bleaching chemical into the pulp is provided by the pump acting against the throttle of the automatic, level-control valve. The required air-free retention is obtained in the upflow tower.

It is not necessary to use either a tower or a pump mixer if the rules for good bleaching are observed. A sectionalized chest design is shown in Fig. 4. Steam is injected into the stock in an in-line mixer. The heated pulp flows into a baffled zone where air has an opportunity to escape and then into a second baffled zone containing an agitator. Zinc hydrosulfite solution is injected beneath the pulp surface into this agitated zone. The required retention time is obtained in the second and third sections of the chest. Circulation agitators transfer the stock from channel to channel. In this example, air oxidation of the bleaching chemical is effectively prevented by the depth of the stock which is from 8 to 10 ft. The top 1 or 2 in. of exposed pulp is bleached only partially; however, the brightness of the bulk of the pulp is raised to as high a value as would be obtained in a tower design. The system has provisions for maximum air removal, good through air-free mixing, and air-free retention.

Perhaps one of the most attractive features of the hydrosulfite bleaching process is that it can be used in many mills without the installation of any pulp handling equipment. An illustration of how zinc hydrosulfite can be applied in a regular decker chest in which the stock is continuously recirculated is given in Fig. 5. Pulp from a number of deckers falls onto the surface of the stock which is continually moved around a mid-feather. Zinc hydrosulfite solution is injected ahead of one of the circulation agitators continuously. The rate of chemical addition is paced with the approximate rate

of pulp withdrawal from the chest. When required, steam is injected into the chest to raise the bleaching temperature. In many modern mills, decker chest temperatures of 120 to 140°F. are available and the addition of steam is not required. If a sequestering agent is added, it is usually injected into the chest on the side opposite to the hydrosulfite introduction point, preferably ahead of the second agitator.

There are a number of differences between the decker chest system and the chest bleach plant illustrated in Fig. 4. The freshly deckered stock contains some entrained air. The oxygen in this air has an opportunity to react with the hydrosulfite before escaping to the atmosphere. Mixing is somewhat slow because any stock which gets through the circulator without being contacted by fresh hydrosulfite solution can take 10 min., in a large system, before reaching the injection point a second time. There is also an opportunity for some short circuiting—i.e., passing of pulp straight to the chest discharge—to occur. One final difference is that in the chest and tower systems, all of the stock is exposed to the full concentration of zinc hydrosulfite applied. This is not true in the decker system. When much of the stock passes the chemical addition point, it has been diluted with previously treated pulp. The concentration of hydrosulfite, based on the liquid present, is probably less than the calculated value. For example, 1.0% may be applied but the highest concentration in contact with most of the fiber may be equivalent to 0.3%.

The major advantages of the decker chest as a bleaching vessel are: (1) the stock is usually warm and ready to bleach; and (2) the cost of the entire bleaching installation is that for equipment for preparing the zinc hydrosulfite and sequestering agent solutions.

A comparison of the efficiency of bleaching in a decker chest and in a chest system similar to that shown in Fig. 4 is given in Fig. 6. The lower of the two curves represents the response of stock bleached with various concentrations of zinc hydrosulfite in a decker chest and the upper curve represents the results obtained with practically the identical pulp under almost the same bleaching conditions in the chest system. Both of these curves were plotted from data taken in the same mill.

It is apparent from these curves that a substantial sacrifice in efficiency occurs when the decker chest is used. For example, to obtain 8 points of brightness increase in the bleach plant, requires 0.38% zinc hydrosulfite. In the decker chest, 0.57% zinc hydrosulfite is necessary to achieve this same increase. In terms of cost, the difference in concentration of

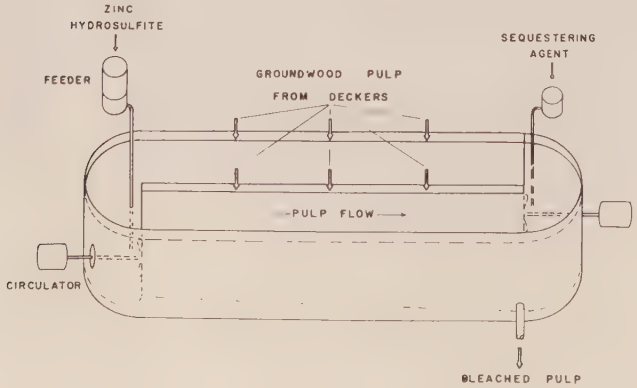


Fig. 5. Decker chest bleaching

the bleaching chemical required for 8 points in the chest system is equal to a saving of $0.92 per ton of stock. The bleaching response with 1.0% zinc hydrosulfite in the decker chest is 10.3 points and, from an extrapolation of the upper curve, in the bleach plant the increase is at least 12 points.

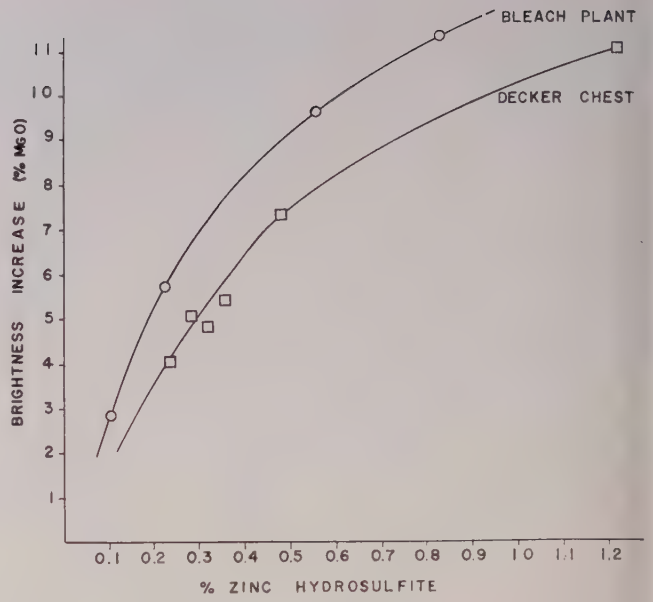


Fig. 6. Plant bleaching results with zinc hydrosulfite

Data were taken two months apart in the same mill. The bleaching conditions were: 1.5–3.0 hours of retention time, 130°–135°F. reaction temperature, and 4 per cent consistency. Sodium tripolyphosphate was used at 0.2 per cent concentration in both cases.

Although the bleach plant is superior to the decker chest system, the cost of bleaching in the latter is remarkably low. The cost per point of brightness increase at the 8-point level is 25 cents per ton of stock in the bleach plant and 35 cents in decker chest.* The first value is unusually low and the latter would be an acceptable cost in practically any mill.

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5. Back, *Tappi* 39, No. 4: 107A (1956).
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Presented at the meeting of the Maine-New Hampshire Section of TAPPI, held in Portsmouth, N. H., June 9–11, 1961.

* The cost in the bleach plant was calculated as follows: 7.6 lb. of zinc hydrosulfite per ton of stock at 21.5 cents per lb. plus 4.0 lb. of sodium tripolyphosphate at 9.0 cents per lb.; in a decker chest: 11.4 lb. of zinc hydrosulfite plus the same quantity of sodium tripolyphosphate.

LETTERS TO THE EDITOR

To the Editor, *Tappi:*

I am writing to express my appreciation and criticism of the paper, "An Analysis of Air-Impingement Drying," presented at the Fifteenth Engineering Conference last fall by Messrs. R. A. Daane and S. T. Han, and published in the January, 1961, issue of *Tappi.*

There is some uncertainty in my mind as to the proper basis of correlation of their experimental data. However, the method used coincides with their mathematical treatment, and the data are sufficiently well represented on their correlation curves. I particularly wish to compliment these men on a concise job of mathematical development.

My chief objection lies not with their data and most cer-

tainly not with the mathematical treatment but with the geometry assumed as the basis of comparison of performance between two dimensional (slotted orifice) and round jets. The geometry used for two dimensional jets was $^1/_4$ in. wide slots, spaced about 22 in. apart, and mounted less than $^3/_4$ in. from the surface. The geometry used for the round jets was $^1/_4$-in. holes, spaced about 2 in. apart, and mounted less than $^3/_4$ in. from the surface. On this basis, I have duplicated their calculations, and using their data, have secured the same results.

$$C_2 \text{ (slots)} = 0.00264\ K^{-0.26}$$
$$C_2 \text{ (round jets)} = 0.00285\ K^{-0.26}$$

Thus the authors show that round jets will provide about 8% more drying effectiveness with equal fan power input and equal operating temperature and humidity.

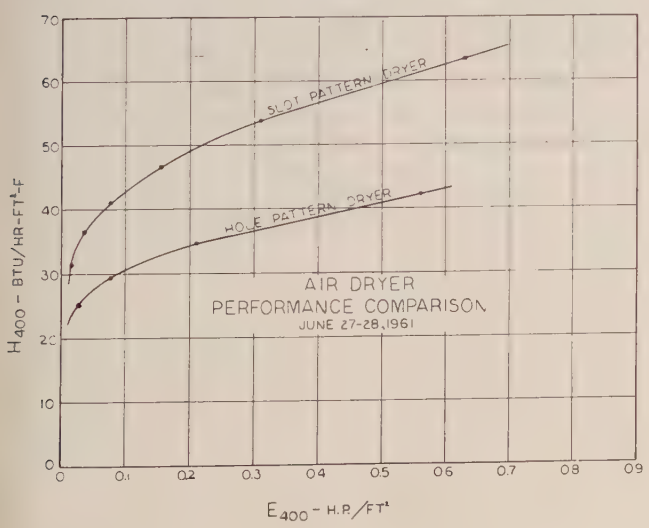
A comparison based on more realistic drier designs such as are currently being built does not support the above conclusion. Such a design would be, for two-dimensional jets, 0.025 in. wide slots, spaced 1.2 in. apart, and mounted $^1/_4$ in. from the surface. The round jet design would be $^3/_8$-in. holes, spaced just under 3 in. apart, and mounted 1 in. from the surface. On this basis I have duplicated their calculations (appended), and using their data, have secured the following results:

$$C_2 \text{ (slots)} = 0.00422\ K^{-0.26}$$
$$C_2 \text{ (round holes)} = 0.00260\ K^{-0.26}$$

As applied to existing drier designs the, slotted orifices should provide about 62% more drying effectiveness with equal fan power input and equal operating temperature and humidity.

The authors do, however, point out the fact that no allowance has been made in the case of the two-dimensional jet for the deleterious effect of flow interference. At the request of an interested paper manufacturer, I have run comparative performance tests on my testing apparatus to determine how much loss occurs as a result of interference. Without going into detail on our test work, the appended performance curves with data points indicated shows that the performance of the two-dimensional jets is consistently 43% higher for the realistic drier designs described above. Thus the interference loss is clear, but a very large discrepancy in performance between practical designs exists, the slotted type design being clearly and indisputably greatly superior to the round hole design.

A further conclusion which can be drawn from the paper and from the test work is that a given size of round hole drying hood would, in practice, need to be supplied with approximately six times more fan horsepower to produce a drying effect equal to the same size of slotted orifice hood.



I would like to extend an invitation to any interested persons to visit my test site to observe reruns of the above tests. I will gladly furnish cumulative authentication upon request.

T. A. Gardner
Pulp & Paper Engineering
Marathon, Div. of American Can Co.
Menasha, Wis.

Solutions for Two-Dimensional Jets

I. $b = 0.25$ in., $X = 11.3$ in., $\frac{x}{b} = 45$, $A_f = 0.011$, $\frac{y}{b} < 3$

$$C_2 = \frac{\bar{h}}{p^{m3}} = (0.048)\left(\frac{1}{K}\right)^{0.26}\left(\frac{b}{X}\right)^{0.74}\int_0^X \phi_2\alpha\left(\frac{x}{b}\right)$$

From Fig. 3:

$$\int_0^X \phi_2 d\left(\frac{x}{6}\right) = 0.918$$

$$C_2 = (0.048)\left(\frac{1}{K}\right)^{0.26}\left(\frac{1}{45}\right)^{0.74}(0.918) = 0.00264K^{-0.26}$$

II. $b = 0.25$, $X = 6.0$, $\frac{x}{b} = 24$, $A_f = 0.021$, $\frac{y}{b} < 3$

From Fig. 3:

$$\int_0^X \phi_2 d\left(\frac{x}{b}\right) = 0.581$$

$$C_2 = (0.048)\left(\frac{1}{K}\right)^{0.26}\left(\frac{1}{24}\right)^{0.74}(0.581) = 0.00265K^{-0.26}$$

III. $b = 0.025$, $X = 0.60$, $\frac{x}{b} = 24$, $A_f = 0.021$, $\frac{1}{b} < 3$

From equation (10):

$$h \backsimeq \left(\frac{1}{b}\right)^{0.22}$$

From Part II above:

$$C_2 = 0.00265K^{-0.26}\left(\frac{0.25}{0.025}\right)^{0.22} = 0.0044K^{-0.26}$$

IV. $b = 0.025$, $X = 0.60$, $\frac{x}{b} = 24$, $A_f = 0.021$, $\frac{y}{b} < 10$

From Fig. 2: As $\frac{y}{b}$ increases from 3 to 10, h decreases as $\left(\frac{24}{25}\right)$

$$C_2 = 0.0044K^{-0.26}\left(\frac{24}{25}\right) = 0.00422K^{-0.26}$$

Note: Solutions for round jets were identical with solution given and solution shown in Fig. 6 ($C_2 = 0.0026$).

Testing Equipment

To the Editor, *Tappi:*

We will appreciate your making a correction in the listing of testing equipment suppliers, to which some of your readers may still be referring after its publication in the January, 1960, issue.

W. & L. E. Gurley is the sole manufacturer of apparatus covered by the following:

TAPPI Standard T 460 m-49, Gurley Densometer
TAPPI Standard T 479 sm-48, Gurley-Hill S-P-S Tester
TAPPI Standard T 441 m-58, Cobb Sizing Tester

In the previous list it was indicated that this equipment was supplied by TMI. Testing Machines, Inc., is a valued dealer of ours but is not the manufacturer, and we believe that the records should be corrected.

R. G. Betts, *President*
W. & L. E. Gurley
Troy, N. Y.

Symposium on Wood Preparation

Proceedings of the 46th Annual Meeting of TAPPI

NEW YORK, N. Y., FEB. 21, 1961

The Sulfite Pulping Session II of the Forty-Sixth Annual Meeting of the Technical Association of the Pulp and Paper Industry convened at 9 o'clock, Tuesday morning, Feb. 21, 1961, at the Commodore Hotel, New York, N. Y., Warren A. Chilson, United States Forest Products Laboratory, Madison, Wis., presiding.

Introductory Remarks—Warren A. Chilson—Moderator

The subject of our symposium, wood preparation, has received over the years, as you know, serious attention by many of the people in our industry, especially those involved in the manufacture of sulfite pulps. The operators of our sulfite mills have known for some time that chips made with equipment having dull knives produce weak pulps. Research workers realizing that there are underlying causes for these strength losses have made various studies of the effect of damaged wood on the quality of sulfite pulps. A little over 20 years ago Hagglund and Bildt found that wood heated in water, drum barked hot and chipped hot gave pulp of a lower tensile strength than the average pulp produced by the mill. These workers also found that wood which had been crushed or hammered gave pulp which was abnormally weak and developed low strength on beating. Green and Yorston reported losses as high as 50% in burst and tear and 35% in tensile strength due to crushing the wood. In classification tests they found that pulp from crushed wood contained fewer long fibers. Only 18% of pulp from these damaged fibers was retained on a 28-mesh screen, while the pulp made from uncrushed wood contained 72% which was retained on a 28-mesh wire. Logan and his co-workers, Sepall, Chollet, and Little observed sulfite pulp strength losses almost as much as Green and Yorston when wood was subjected to compression in the fiber direction. Also, they found that the pulp from this compressed wood had a lower chlorine number than pulp from wood which had not been compressed. Anderson of Crown-Zellerbach removed the bruised ends from mill run chips and increased the maximum burst of the sulfite pulp by about 20% and the initial tear by 5%. His hand-cut chips produced sulfite pulp with 33% higher maximum burst and 30% higher initial tear than the pulp from regular mill chips.

The four papers listed in the program will first be presented and will be followed by a discussion.

The Influence of Wood Damage on Pulp Quality

J. E. STONE

The present state of our knowledge is reviewed with regard to the influence on pulp quality of mechanical treatments of wood prior to and during pulping. Two types of damage are distinguished: (1) overt damage involving cutting and fragmentation of fibers, (2) latent damage which is only developed by the cooking liquor. The first type affects the properties of all pulps, the second only affects acid pulps because the latent damage is developed by acid hydrolysis. The review concentrates on latent damage, shows that it occurs naturally in wood, is produced by mechanical handling (particularly chipping), and results from axial compression and disalignment of cellulose microfibrils in the cell wall. Damage is not proportional to the energy applied to the wood during deformation, more damage being caused when the wood is hot than when cold. Damage is not confined to the region of gross failure, but extends beyond this through the body of the specimen. Attempts to reduce acid susceptibility in wood have failed. It is shown that the yield and chemical composition of pulp is not changed even by severe damage. The viscosity of cellulose is greatly reduced. Suggestions are made for future work in this field.

J. E. Stone, Pulp and Paper Research Institute of Canada, 3420 University St., Montreal, P. Q., Canada.

It was more than 20 years ago that Yorston and Green pointed out the losses in pulp quality which can result from the damage caused to wood by the action of a chipper knife, suggesting that a 15% improvement in the strength characteristics of sulfite pulp could result from the elimination of this damage. An upgrading of this magnitude would be very worth while, and more than is usually expected from ringing the changes on cooking liquor composition, time, temperature, etc. It is not surprising therefore that the sulfite industry, under the pressure of competition for higher quality, has taken increasing interest recently in the subject of wood damage and its influence on the properties of paper.

DAMAGE

Definition

The word "damage" will be used quite liberally throughout this review, so it may be as well to say one or two things about wood damage which, although rather obvious, are nevertheless important. Wood is certainly damaged when pulp is made from it, and fibers are damaged in the beater, but these operations are necessary to the production of paper as we know it today. Wood can be considered damaged by some treatment only if it results in a paper product with inferior qualities to that obtained if the treatment is omitted or modified. Wood which may be seriously damaged for sulfite pulping may be perfectly satisfactory for kraft, and wood designed for tissue manufacture may be considered damaged even though for board production it is eminently suitable. And the dissolving pulp industry will no doubt have an entirely unique criterion of what does and does not constitute damage. In other words, damage is a relative term which depends on the product and the method of manufacture.

Two quite different types of damage should be distinguished. One, the obvious kind, is thec utting of fibers by, for example, a chipper knife, and the tearing and fragmentation of fibers by the shear and splitting forces at the plane of separation between chip and parent log. No pulping process is going to put these fibers together again, so for many purposes they would be considered damaged, regardless of whether the kraft or sulfite process were to be used for pulping. This overt damage is of relatively minor importance

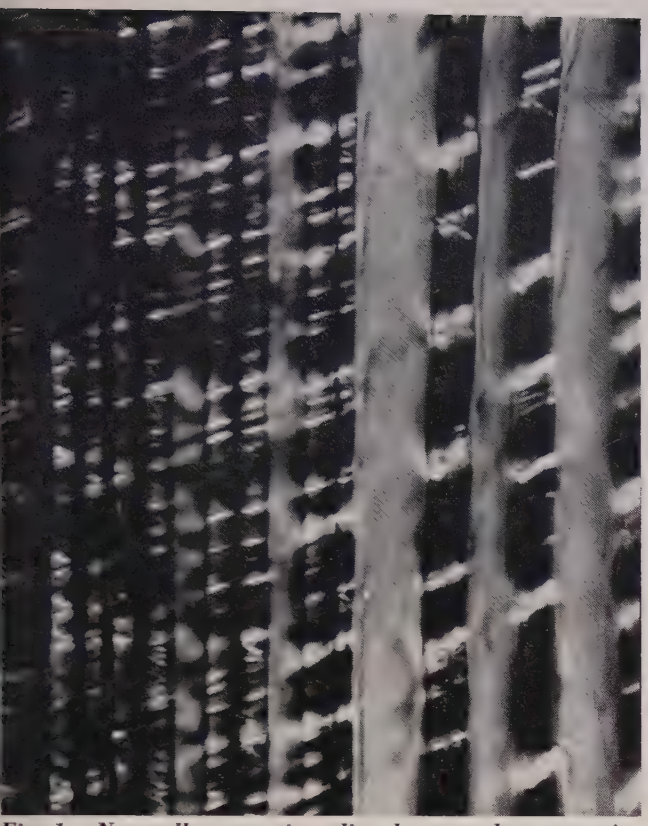


Fig. 1. Naturally occurring slip planes and compression failures in black spruce tracheids. Photographed between crossed nicols

compared with the more insidious form which occurs away from the cut surfaces in the body of the chip and may affect a considerable percentage of the total fibers present. This damage, sometimes referred to as acid susceptibility, is latent in form, far from obvious by inspection, and requires the use of a chemical developing agent to make it become apparent. It may be likened to the latent image on a film which also becomes apparent only on proper development, and unfortunately acid sulfite liquor is an excellent developer of latent damage. Kraft liquor is a poor developer. This review, being concerned chiefly with latent damage, is mainly of interest therefore in connection with sulfite pulping.

Naturally Occurring Damage

Wood normally contains a certain percentage of fibers with discontinuities in the cell wall, and these discontinuities are points of mechanical weakness and greater susceptibility to chemical (particularly acid) attack. These discontinuities have been known for many years and are described as cell wall deformations or dislocations, slip planes, minute compression failures, acid-susceptible areas, and so on, depending on the observer and the test used to distinguish the material. The discontinuities differ somewhat in form, but the differences are in degree rather than kind, and for the purposes of this discussion they can all be considered as having several important properties in common. One of these is the ability to be observed in polarized light, a property resulting from the birefringence of cellulose microfibrils and the change in direction of the microfibrils in the regions of discontinuity. Figure 1 shows an example of naturally occurring cell wall discontinuities in a spruce tracheid. Another distinguishing feature is the different reactivity of stains, acids, and acetylating agents in the regions of cell wall deformation

The occurrence, structure, and properties of cell wall deformations have been studied and reviewed at length by Wardrop and Dadswell (*28*), and they state that virtually all longitudinal sections of all species studied—hardwood and softwood—contain slip planes to some extent. Moreover, textile fibers such as flax, jute, hemp, and ramie contain distortions of the cell wall known as dislocation marks which are strikingly similar to the minute compression failures of wood. Green (*8*) has also mentioned that after many years of examining softwood tracheids, the conclusion must be reached that minute crinkles or folds or dislocations in the cell wall are of common occurrence in what is usually considered normal wood.

The effect of acid treatment is to break the fibers at the region in the cell wall where the dislocations occur, and the number of broken fibers increases with increasing time and acid concentration (*28*). Wardrop and Dadswell conclude that the acid hydrolysis causes local breaking of the fibers due to increased micellar surface area and therefore faster hydrolysis at the dislocation marks.

Cell wall deformations very similar to those found naturally can be induced in wood fibers by bending the wood or applying compressive loads parallel to the fiber axis. This suggests that similar mechanical forces must have been acting on the living tree. These forces could be produced by bending of the tree through wind action or uneven snow loading, through shrinkage due to drying, or through growth stresses, and Wardrop and Dadswell in their review conclude from the evidence that growth stresses are probably the most important of these factors. They quote the views of Jacobs (*14*) that woody tissues are laid down in a state of longitudinal compression, the pressure at the center of a 3-in. diam. stem being of the order of 1500 p.s.i. This pressure, coupled with the loads imposed on cells from the sheer weight of the stem above, are considered to result in the discontinuities observed so widely in woody tissue.

From the viewpoint of the sulfite pulp producer there would seem to be little chance of overcoming these inherent weak spots in the fiber, and therefore the reduction in fiber length and strength which results from acid liquor attacking these areas may be a shortcoming of the sulfite process with which we have come to terms. Before being overly concerned with the naturally occurring acid-susceptible regions in wood fibers however, the elimination of man-made acid susceptibility should be tackled. Qualitatively and quantitatively this is of considerably greater importance than natural damage, and unlike the latter it is more or less under our control.

Man-Made Damage

Nature and Magnitude of Stresses Which Degrade Wood. The knowledge that mechanical stresses applied to wood will lead to poorer sulfite pulp is not new. In 1936 Hagglund (*11*) showed that hand-made chips give exceptionally strong pulps, whereas crushed or hammered wood gives a

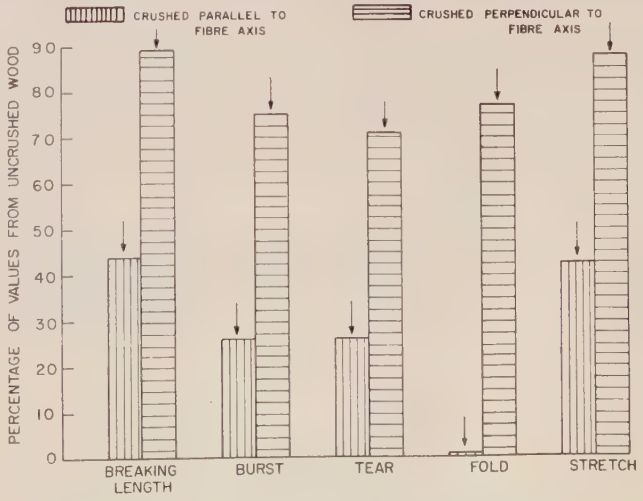


Fig. 2. Reduction in strength of spruce sulfite pulps due to compression of wood before pulping

Table I. Screen Classification

Deformation, %	Unbeaten					Beaten 500 revs., PFI mill				
	R14	14/28	28/48	48/200	Pass 200	R14	14/28	28/48	48/200	Pass 200
0	34.2	37.1	17.9	4.2	6.6	25.3	41.6	15.6	7.3	10.2
5	13.4	50.2	21.3	9.3	5.8	3.1	35.9	20.5	24.5	16.0
10	14.1	44.7	26.5	9.2	5.5	1.9	25.5	20.2	31.6	20.8
20	0.8	36.0	31.1	24.7	7.4	0.3	10.8	13.2	46.3	29.4
35	0.2	28.8	34.5	28.5	8.0	0.1	4.9	8.8	56.0	30.2
50	0.2	9.6	33.9	46.0	10.3	0.1	1.3	5.8	64.1	28.7

very poor pulp. Bildt (*3*) confirmed this and also showed that a hammer blow on the end grain of wood is as damaging as a slowly applied compressive load. Bildt and Hagglund (*3, 12*) also showed that wood chipped while hot is degraded more during sulfite cooking than wood chipped cold. Empirical experiments of a similar sort have continued to the present day, but in 1939 and 1940 an examination of the nature of the stresses which degrade wood was made by Green and Yorston (*6, 7, 29*), which has led to a much better understanding of the problem.

Green and Yorston used blocks of wood and applied a compressive stress either parallel or perpendicular to the grain direction. They also bent wood in the form of a beam to give compression on the concave and tension on the convex side. Torsional stresses were applied to a stick by twisting to destruction. Damage was detected by pulping the wood with either acid sulfite or kraft liquors and evaluating the pulps, and acid susceptibility was also detected qualitatively by means of mineral acid treatment and testing for embrittlement with a knife. They found that (1) compression of wood parallel to the grain causes much more damage than compression perpendicular to the grain; (2) tensile stresses do not cause damage; (3) torsion, although apparently unaccompanied by axial compression produces at least 25% damaged wood; (4) axial compression has little effect until the stress approaches the ultimate strength of the wood; (5) kraft liquor degrades compressed wood much less than sulfite liquors; (6) commercial chips contain damaged wood as a result of axial compression of the fibers by the chipper knife, and this damage is maximum at one end of the chip.

Some of these findings have been examined in more detail recently by the writer. In the first study (*26*) spruce and tamarack in the green condition were sawed into blocks and compressed to one-half the original thickness in directions either parallel to or perpendicular to the grain. The wood was carefully cut into chips and pulped by acid sulfite, bisulfite, neutral sulfite, and kraft liquors. The effect of using different cooking liquors will be discussed later. Using acid sulfite liquor, the results obtained with spruce are shown, in an abbreviated form, in Fig. 2.

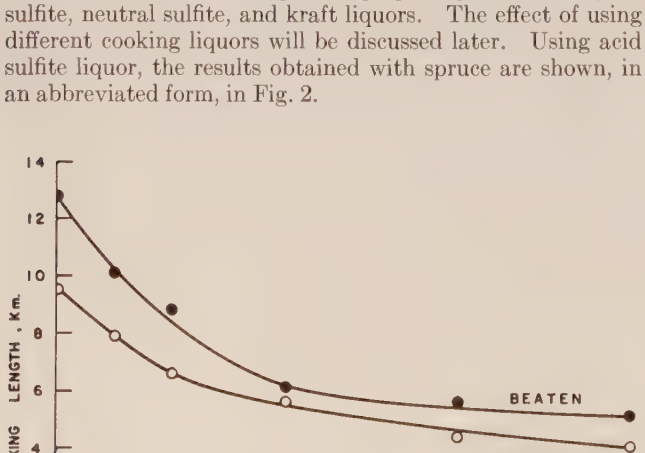


Fig. 3. Influence of axial compression of wood on the tensile strength of beaten (5000 rev. in PFI mill) and unbeaten pulps. Yields ca. 50%

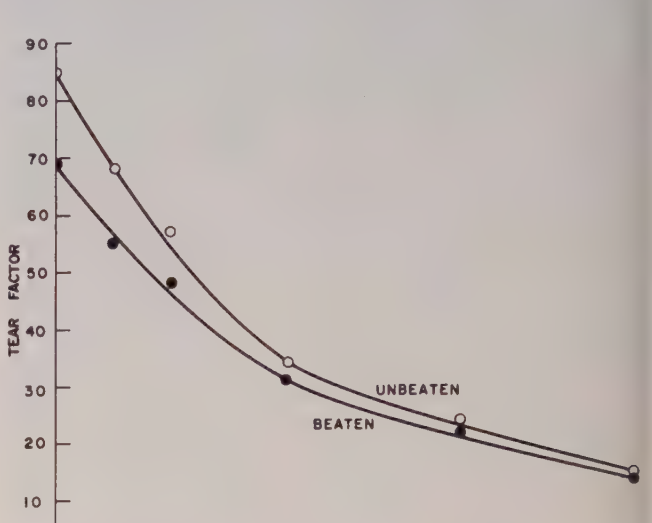


Fig. 4. Influence of axial compression of wood on the tearing strength of beaten (5000 rev. in PFI mill) and unbeaten pulps. Yields ca. 50%

In confirmation of earlier findings, axial compression is seen to be much more detrimental to pulp quality than compression perpendicular to the fiber axis. Thus, with axial compression the burst is 26%, tensile 44%, tear 26%, and folding endurances less than 1% of normal; this compares with 75, 90, 71, and 77%, respectively, when compression is in the other direction. These latter figures, while certainly better than those for axial compression, represent a distinct loss of pulp quality and show that compression perpendicular to the fiber axis cannot be ignored entirely as a degradative process. It will be noted that the folding endurance is particularly affected by axial compression of wood, and can therefore be used as a sensitive detector of this kind of damage.

Recently a more detailed study was carried out on the effects produced by axial compression of spruce blocks (*27*). The deformation was varied between 5 and 50%, sulfite pulp was produced, and the chemical, physical, and morphological changes induced by the compression were examined. Some of the results obtained are shown in Figs. 3, 4, and 5 and Tables I and IV.

It is seen that damage is appreciable at 5% deformation and virtually complete (if folding endurance is taken as the criterion) at 35%. Between 0 and 5% deformation it is more difficult to get reliable data because of the natural variations in wood quality from block to block which tend to mask the small effect of applied stress in this region of comparatively small strain. Spruce fails in compression parallel to the grain at about 0.2% deformation and the proportional limit at somewhat less than this. It would be expected that strains within the elastic region would not cause damage, but as soon as the elastic limit was exceeded the damage should increase in amount as more and more of the wood substance becomes involved in inelastic deformation. In practice, using paper properties as criteria, no damage could be detected with deformations up to 1%. Between 1 and 5% deformation the strength decreased more or less

Table II. Effect of Temperature During Deformation

Temperature, °C.	Deformation, %	Energy absorbed, ft.-lb./lb. o.d. wood	C. S. freeness,[a] ml.	Bulk, cc./g.	Tear factor	Breaking length, m.	Stretch, %	Double Fold	Zero-span tensile kg.
25	0	0	347	1.22	66	13,200	4.5	2810	15.76
25	10	1220	211	1.23	30	6,540	2.3	65	9.27
25	20	2320	155	1.16	24	6,230	1.8	26	7.55
25	35	4300	162	1.17	18	5,760	1.6	5	6.92
95	0	0	360	1.24	69	12,660	4.6	4230	15.42
95	10	603	178	1.16	24	6,780	1.8	20	8.38
95	20	1200	206	1.19	18	5,720	1.9	6	7.03
95	35	2480	184	1.22	15	5,330	1.9	6	7.29

[a] Beaten for 5000 rev. in PFI mill.

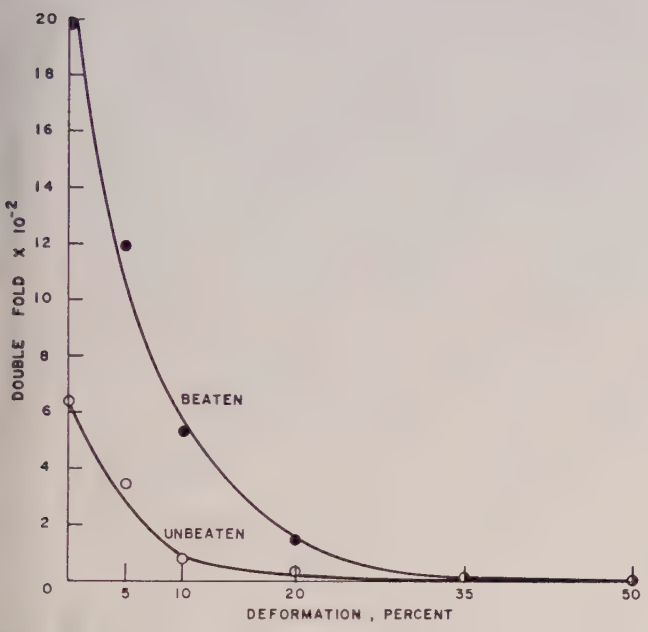


Fig. 5. Influence of axial compression of wood on the double fold strength of beaten (5000 rev. in PFI mill) and unbeaten pulps. Yields ca. 50%

linearly. This is similar to the findings of Logan, *et al.* (*18*), who detected damage in spruce blocks only after a deformation of 1.2% was exceeded.

Distribution of Damage. It will be appreciated that when a block of wood is deformed by compression beyond the point of failure, the measured deformation is a combination of greater deformations in the plane of failure and lesser deformations in the remainder of the block. In other words the strain is not uniformly distributed over all the fibers in the block, and some will be damaged much more than others. In order to examine this distribution of damage, a block of spruce 9 in. high and 25 sq. in. in cross-section was compressed 6.5% and was then sawed into 8 slabs about 1 in. thick. These slabs were pulped separately, and the physical properties of each are shown in Fig. 6. The block is seen to have been damaged at both ends and escaped damage in a 3-in. section near the middle. Visual examination of the block after compression showed a small amount of buckling in sections 7 and 8, but the remainder of the block appeared unchanged. Nevertheless, considerably more of the block than sections 7 and 8 were damaged, which means that visual examination is an unreliable guide. A number of other blocks were compressed and sectioned in a similar manner, and although the distribution of damage was unique for each block it was apparent that in every case the damage was more widespread than might have been expected.

Another demonstration of the widespread damage which occurs in a compressed block is afforded by Table I. These pulps were obtained as previously described from blocks compressed 5, 10, 20, 35 and 50%, and fiber classification was made with a Bauer-McNett classifier. It will be noted that with no compression the pulp after beating for 5000 rev. in a PFI* mill contains 25.3% of long fibers which remain on the 14-mesh screen. When the wood is compressed 5% only 3.1% of long fibers remain after beating. This suggests that 88% of the long fibers in the wood block had been affected by the 5% compression. At 10% deformation the percentage rose to 92.5%.

Influence of Wood Temperature During Compression. Blocks of water-saturated spruce were compressed at either room temperature or 95°C. and the effect on physical properties of the pulps is shown in Table II. It is apparent that more damage is produced in hot wood than in cold, even at the same percentage deformation. It had been thought that the damage might be related to the work required to deform the wood, and that at elevated temperatures there would be so much less energy required to produce a given deformation that the damage would be correspondingly less. This is evidently not the case. About half as much energy is required at 95°C. as at 25°C. to produce the same deformation, but instead of the damage being half as great it is actually somewhat greater. Heating the wood therefore makes it easier to do more damage. These results confirm the experience of Hagglund (*12*) and Bildt (*3*) and others that chipping damage is increased by raising the temperature of the wood.

* Paperindustries Forskings Institutt mill, Oslo.

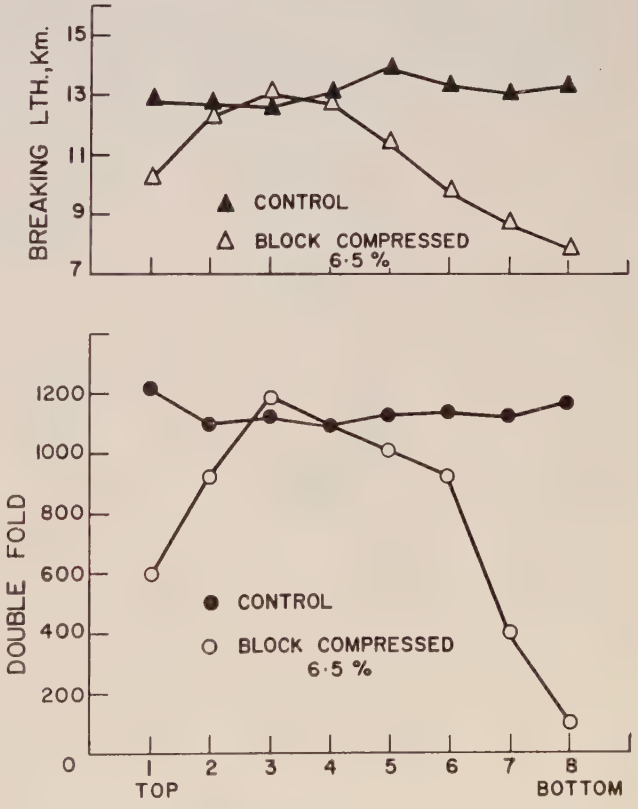


Fig. 6. Distribution of damage in a 9-in. block compressed axially 6.5%, compared with the natural variations in an unstressed "control" block

Chipping

That chipping does produce damaged wood has been demonstrated by many investigators (*1, 2, 12, 13, 18, 20, 24, 25, 29*), usually by comparing the pulp properties with those produced from carefully prepared hand-made chips. Invariably the hand-made chips produce the better pulp. It has also been demonstrated (*2, 6*), by sawing commercial chips in half and pulping each half separately, that the damage is greater at one end than the other. The reason for this becomes apparent from an examination of the action of a chipper knife in severing a chip from the parent log, shown diagramatically in Fig. 7.

As the knife enters the wood the chip being formed must accommodate itself to the bevel of the knife and it does this in two ways: (1) by deformation of the wood parallel to the fiber axis and (2) by multiple splitting and bending of one end of the chip as shown in the diagram. Ultimately, as the knife penetrates deeper into the wood, the compression and bending of the chip produces a splitting action which parts the chip from the log. From what has been said previously about the effect of compression parallel to the fiber axis and of bending, it is clear that damaged fibers must result. The amount of damage should be a minimum at the tip of the knife and increase to a maximum at the outer side of the chip as shown.

The multiple splitting at the end of a chip is difficult to analyze in terms of percentage compressive deformation, but if we assume that at some instant there is just compression and no bending, the amount of axial deformation can be calculated from the geometry of the system. This has been done for three different chip thicknesses, chip lengths, and knife angles in Table III. The deformations shown are the maximum realizable from geometric considerations, and refer to the upper surface of the chip. The average for the whole chip would be one-half these values. The minimum deformation should be produced with a long, thin chip cut with a knife of small angle, although in practice, of course, the chip length and thickness and the knife angle are not usually independent variables. The purpose of this table of hypothetical values is to demonstrate that large deformations, well above the failure point of the wood, could occur during chipping. Buchanan (*4*) of these laboratories has measured the strain in the body of a chip during its formation in a slow-speed, laboratory chipping apparatus and

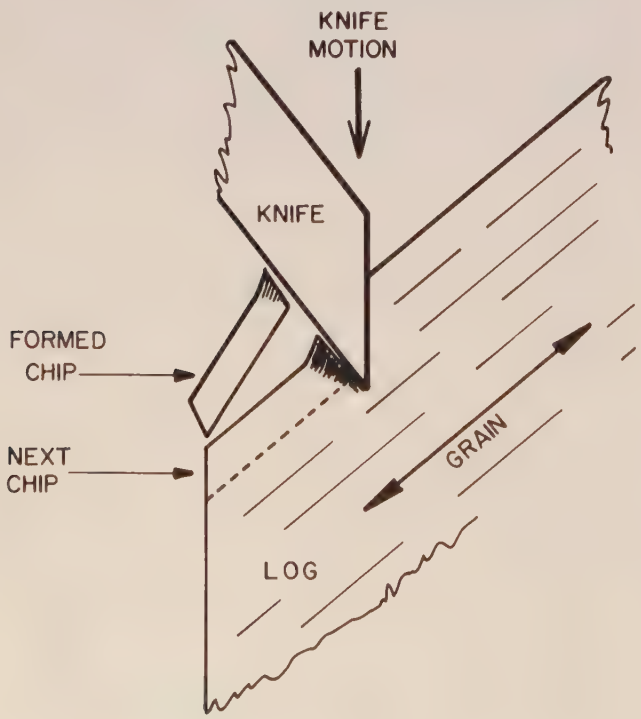


Fig. 7. Action of a chipper knife

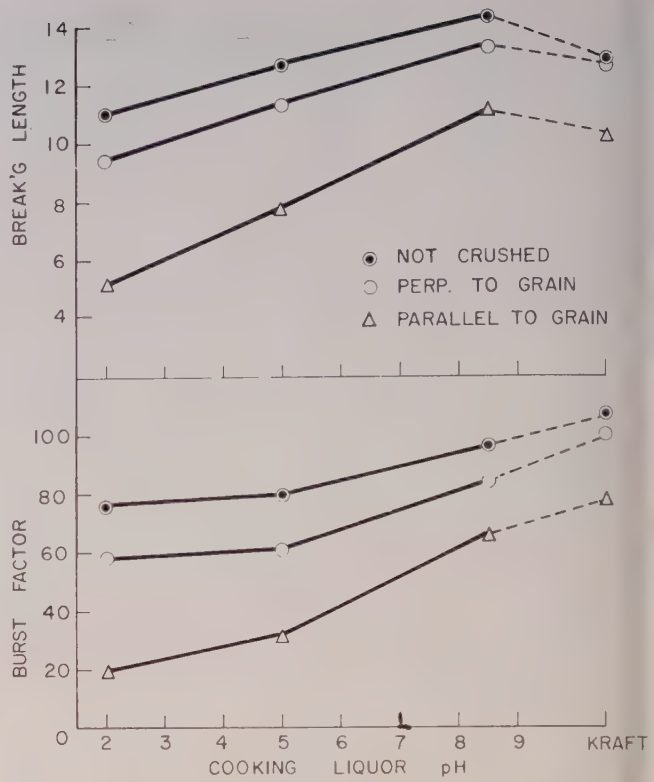


Fig. 8. Influence of cooking liquor pH on properties of pulp from eastern larch. Yields ca. 50%

has detected strains of about 1% in the region away from the knife. It may reach 2% for wet wood and fall as low as 0.5% for dry wood. The strain close to the knife however, in what is known as the damaged end, must be considerable, probably well over 10%, and even 1% in the body of the chip is in excess of the failure strain and may therefore produce a small amount of damage. Buchanan has also found that with knife angles of 30° or less the chips are formed by splitting, whereas with 40 and 50° knife angles the number of chips formed by shearing rather than splitting increases to 33 and 61%, respectively.

If a chipper is to be designed or operated so that the loss in pulp quality is to be kept at a minimum, it is necessary to avoid compressive deformations parallel to the grain direction as far as possible. Other considerations, such as uniformity of chip size, production of suitable dimensions for effective liquor penetration, and production of a chip shape which can be handled easily and packs efficiently into a digester but still permits good liquor circulation, are all important, as are the energy consumption in chipping, the initial cost of the chipper and the ease and cost of maintenance. Some of these considerations may be incompatible with the avoidance of compression damage, but it would be unfortunate, particularly for sulfite pulp producers, if chipper manufacturers completely ignored the importance of fiber quality. In a series of papers Murto and co-workers (*21*) have obtained very useful information on the influence of wood moisture, chipper geometry, temperature of chipping, wood species, and other factors on

Table III. Maximum Deformation in a Chip from Consideration of Geometry of System

Chip length, in.	*Chip thickness, in.*	*Percentage deformation[a]* — *Knife angle* 25°	35°	45°
1/2	1/8	11.6	17.5	25.0
	1/4	23.2	35.0	50.0
1	1/8	5.8	8.7	12.5
	1/4	11.6	17.5	25.0
1 1/2	1/8	3.9	5.8	8.3
	1/4	7.7	11.7	16.7

[a] On upper face of chip. Average for whole chip is one-half these values.

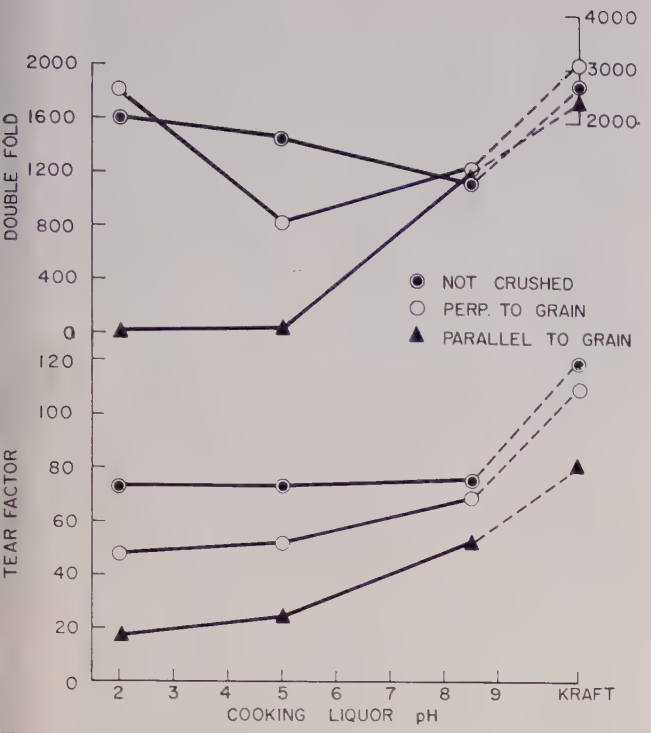


Fig. 9. Influence of cooking liquor pH on properties of pulp from eastern larch. Yields ca. 50%

the amount of chipper fines, energy consumed in chipping, and the extent of damage as shown by dye absorption techniques. This work requires extension in two directions, however. One is to make use of the knowledge that compression parallel to the fiber axis must be reduced to a minimum and study in detail the deformations which actually occur in various parts of a chip during its formation. It might then be possible to modify the operation so that chips are formed with lesser amounts of harmful compression. As mentioned previously Buchanan is doing work of this sort, observing the deformations in a chip while it is being formed by photographing the distortion of a grid pattern drawn on the side of the wood (*4*). Another approach is to evaluate chipper performance, so far as chip quality is concerned, by carrying out sulfite cooks and evaluating the pulp. At the moment there is nothing quite as satisfactory for evaluating chip quality. It gives data which are readily interpretable in terms of real qualities and it shows up damage which is not easily seen in any other way. It is another example of the old saw that "the proof of the pudding is in the eating."

A start has already been made on designing a chipper which reduces the amount of compression damage through a deliberate application of the knowledge that compression perpendicular to the fiber axis is less harmful than compression parallel to the fiber axis. Logan and co-workers (*18*) reasoned that if the knife attacked the side of the log in a tangential direction the bevel of the knife would be applying compression perpendicular to the grain direction, and minimum damage should result. They designed a chipper which cut chips or gouges out of the log with a three-edged cutting tool, leaving land areas of the same width as the chips which were cut off immediately afterward with a slabbing knife.

The exact mode of operation is best seen by consulting their original paper. The chip produced was rather large in area but comparatively thin, averaging $^1/_8$ in., and uniform in thickness, so penetration of cooking liquor was more rapid and uniform than normal. This resulted in shorter cooking times and fewer pulp screenings. The strength properties of sulfite pulps, both bleached and unbleached, were markedly superior to that from regular chips. The new chipper required less power, there was less knife wear, less noise, and the output and feed could be kept constant. Disadvantages were the difficulties in handling, storing, and packing the chips in the digester, the latter factor resulting in perhaps a 10% lower digester charge. Possibly these disadvantages could be eliminated by a change in design or modifications in ancillary equipment for chip handling; in any case, it would appear that the utilization of known principles by those who are concerned with pulp quality can result in substantial improvements in chip quality.

Chip Shredders and Crushers

In order to aid liquor penetration and permit more rapid cooking it has been advocated from time to time that chips be subjected to some kind of shredding or crushing action. Jayme and Grogaard (*9, 15*) studied the use of an Asplund defibrator for this purpose, and Nolan, *et al.* (*22*) have investigated preshredding with a hammermill. In a recent paper Colombo, *et al.* (*5*) describe the effect of passing chips between rollers prior to kraft cooking, with a view to evening out the differences between chips of different sizes. McGovern and Simmonds (*19*) have also described the use of rollers for opening up chips prior to cooking, in their case the pulping chemical being neutral sulfite. Kleinert and co-workers (*16*) fiberized alkali-impregnated wafers in a Waring Blendor and chips in a Sprout-Waldron refiner, the fiberized material being subsequently cooked by an alkaline process.

From the above studies it appears that no method has yet been devised which will fiberize or open up chips without causing a loss in quality when the sulfite process is used for pulping. For alkaline or neutral sulfite pulping, however, there is a possibility that mechanical subdivision of wood chips is not only feasible but also advantageous if the method of subdivision is chosen carefully. The most suitable method seems to be crushing between rollers, and this is reasonable in view of the fact that this type of mechanical action is largely compression perpendicular to the fiber axis with a minimum of fiber cutting. Asplund defibrators, disk refiners, hammermills, and the like may possibly be satisfactory under certain circumstances and for nonacidic pulping liquors only, but there would always seem to be a greater chance of cutting fibers than when a roller press is used.

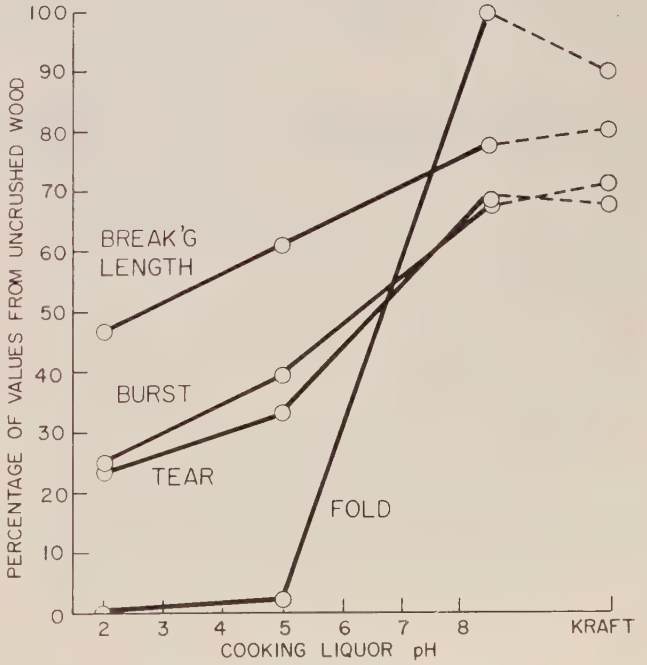


Fig. 10. Influence of cooking liquor pH on the lowering of pulp quality due to wood damage

Continuous Digesters

In moving into, through, and out of a continuous digester the chips are necessarily subjected to some mechanical action. The severity of such action will vary widely with the design of the digester, and the most successful designs for high quality pulp will pay particular attention to the chip feed valve, the conveying mechanism through the digester, and the extraction or blow valve. It is so difficult to avoid mechanical action in continuous digesters that sulfite pulping is still a batch process, but considerable success has been achieved with neutral sulfite, soda, and kraft pulping. Much ingenuity has been shown in the design of equipment, and the types in operation vary widely, but judging from the number of installations and the tonnage of high quality pulp produced, the Kamyr system (*23*) has much to commend it. In this system mechanical damage to the chips when they enter the digester is reduced to a minimum by using a rotary pocket valve which does not compress the chips; transport through the digester is by gravity, with no tumbling action; removal of the cooked chips from the base of the digester is by continuous blowing after local cooling of the charge. With this system there is very little more mechanical action than with a batch digester, and the cooling before blowing has been suggested (*17*) as a possible improvement in batch operation also. For high-speed operation, using small units with a large throughput, the problems are more difficult; but for maximum strength in the pulp it seems essential that the principle of avoiding mechanical action before, during, and at the end of cooking must be adhered to, even for nonacidic liquors.

Effect of Cooking Liquor pH

It is well known, and has been mentioned constantly throughout this review, that the sulfite process is much more sensitive to the presence or absence of wood damage than

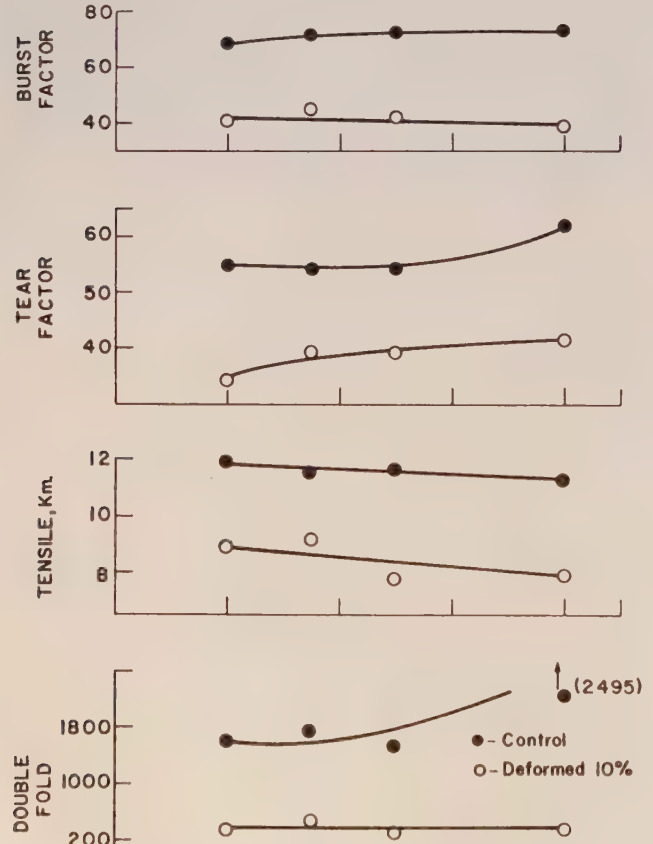


Fig. 11. Influence of cooking time on the degradation of damaged wood

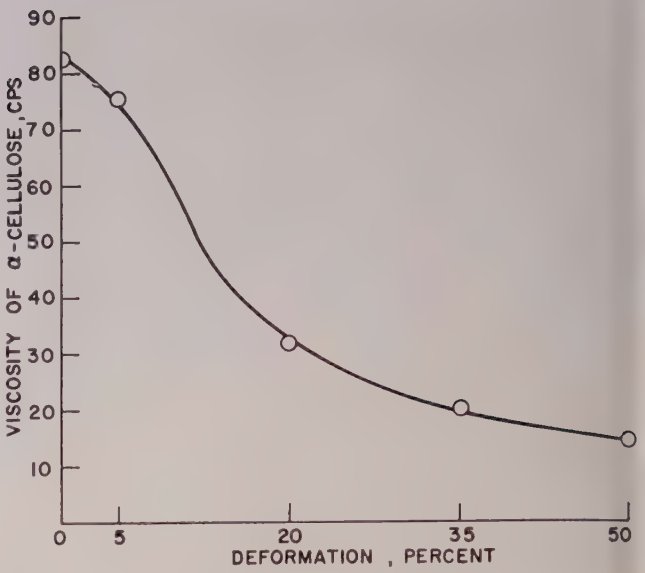


Fig. 12. Influence of axial compression of wood on the viscosity of alpha cellulose

alkaline processes. This is illustrated by Figs. 8 and 9, taken from a previous publication (*26*), which also show the effect of compressing the wood either parallel or perpendicular to the fiber axis. Compression parallel to the fiber axis is seen to be much more detrimental to pulp quality compression perpendicular to the fibers, regardless of the cooking liquor used. Considering axial compression only, the picture is clouded somewhat by the fact that different liquors produce different strength properties even with undamaged wood. However by taking the percentage change in strength a valid comparison can be made, and the result is shown in Fig. 10. The marked improvement in quality on the alkaline side of neutrality is apparent, and on the acid side it appears that pH 5 liquors cause less degradation than liquors at pH 2. This is at variance with the conclusions of Hartler and Sundberg (*13*) who compared sulfite liquors at pH 1.5 and 4.5. Although the hydrogen ion concentration is much lower at pH 4.5 than at pH 1.5, Hartler and Sundberg ascribe the equal degradation observed in their studies to an equal hydrolytic power produced by the higher temperatures used with the less acidic liquor. In other words, the lower acidity is exactly counterbalanced by the higher temperatures or longer times required to give the same degree of delignification. This is rather an important point in view of the current interest in and trend toward sulfite pulping at higher pH values, so a study is under way in these laboratories at the present time to establish the exact relationship between pH and degradation. It would seem to be unquestioned that at pH 8.5 the degradation of damaged wood is less than at pH 2, even though very high temperatures and very much longer cooking times are required.

Effect of Cooking Time on Degradation

Figure 11 shows the effect of varying the cooking time in acid sulfite liquor from 1 to 4 hr. The yield varies from about 63% at the shortest time to 48% after 4 hr. It is seen that the loss of pulp quality due to wood damage is just as pronounced after 1 hr. as it is after 4 hr. cooking (*27*).

THE REASON FOR DEGRADATION OF STRESSED WOOD DURING PULPING

In seeking an explanation for the nature of latent damage in wood, chemical analysis, measurement of cellulose viscosity, and examination of morphological changes to the cell wall by means of light and electron microscopy have been employed.

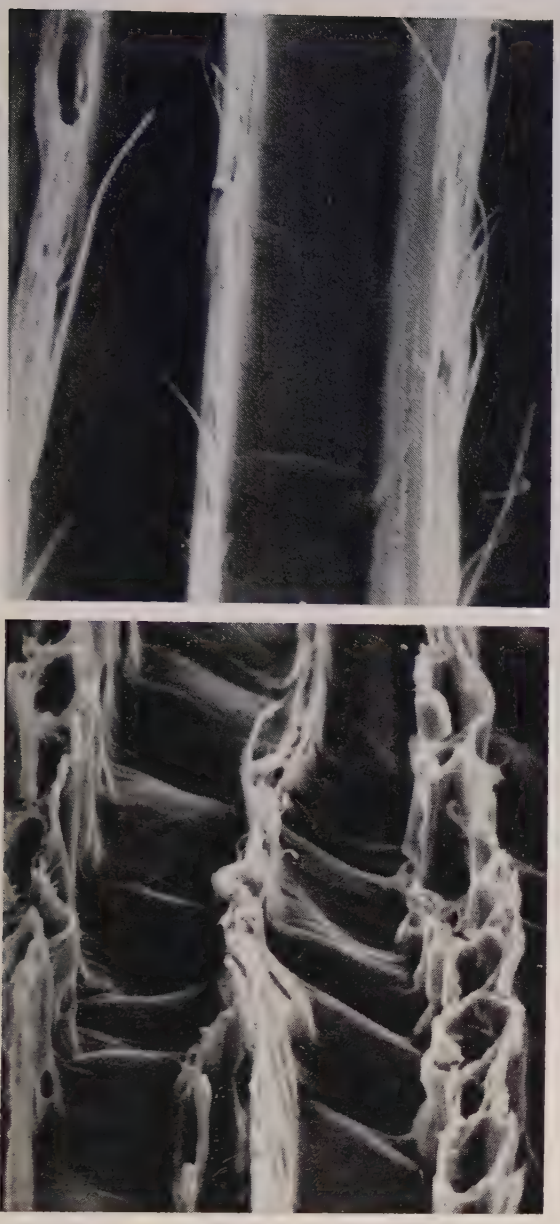


Fig. 13. Electron photomicrographs of spruce tracheids in block compressed 50% while wet and dried under compression to maintain the folds. Upper taken from relatively undamaged area and lower from severely damaged area. Viewed from lumen

Yield and Chemical Composition

The yield and chemical composition of sulfite pulp is largely unaffected by even severe deformation of the wood. This is illustrated by Table IV and is well supported by the data of other workers in this field. The lignin content is slightly, but significantly, reduced as a result of compression damage. This was also observed by Colombo, *et al.* (*5*), for kraft pulping but Kleinert, *et al.* (*16*), found that the amount of lignin removed from wood in a given time by alkaline liquors was reduced by prefiberizing the wood. The results of cellulose determinations and chromatographic analysis of mannose and xylose shown in Table IV indicate a negligible increase in the amount of carbohydrate material dissolved by sulfite liquor from severely damaged wood. Loss of pulp quality cannot therefore be ascribed to a change in chemical composition or the dissolution of some important bonding agent.

Cellulose Viscosity

Figure 12 shows the cupriethylenediamine (CED) viscosity of cellulose obtained from wood deformed to an increasing degree and then cooked by the sulfite process. The viscosity falls sharply with increasing deformation. Cellulose is not dissolved therefore, but chains are broken in several places.

Table IV. Influence of Wood Deformation on Chemical Composition of Pulps

	Deformation, %				
	0	*5*	*20*	*35*	*50*
Yield, %	50.6	50.4	50.9	50.6	51.0
Lignin, %	7.6	7.4	7.0	6.4	6.5
Kappa no.	45.2	43.9	41.4	37.7	36.8
Residual lignin, %	3.8	3.7	3.6	3.2	3.3
Alpha-cellulose, %	75.9	76.0	75.5	75.9	75.3
Residual alpha-cellulose, %	38.4	38.4	38.4	38.4	38.4
Glucose,[a] %	80.2	. .	...	...	82.0
Mannose,[a] %	7.9	...	...	...	.2
Xylose,[a] %	4.3	...	...	...	4.4
CED viscosity, cp.[b]	82.8	75.3	31.9	20.0	14.5

[a] Expressed on unbleached pulp.
[b] Determined on holocellulose, and calculated on 0.5% alpha-cellulose concn.

Morphology

Figure 13 shows electron photomicrographs of spruce tracheids which have been axially compressed in the wet condition and dried under compression to retain the pattern of deformation. The severe corrugation of the walls is apparent. When wood such as this is macerated with hydrogen peroxide–glacial acetic acid reagent, isolated tracheids can be obtained which, in polarized light, show light and dark areas as illustrated in Fig. 14. The pattern of light and dark areas varies widely according to the nature and severity of the mechanical treatment, and Fig. 14 shows a rather extreme case, but they all show that deformation of the fibers or tracheids causes disorientation of the cellulose microfibrils in the cell wall. Cellulose is birefringent, and when the microfibrils in the S_2 layer of the cell wall are arranged in an orderly manner, rotation of the fiber between crossed nicols will cause it to glow in the brightness position and be dark in the extinction position, so the light areas represent parts of the wall which have been rotated or disoriented by the mechanical action.

Figure 15 shows spruce sulfite tracheids swollen in cupriethylenediamine solution and the characteristic ballooning of the S_2 through the S_1 layer is seen. In Fig. 16, the same solution has reacted for a shorter time on tracheids from damaged wood cooked by the sulfite process. Instead of ballooning the cell walls simply disperse. The undamaged tracheids remain as shown in Fig. 15 for an indefinite period in the 0.2 *M* CED used, and a number of the thicker walled tracheids do not balloon at all, remaining rigid and intact.

Fig. 14. Damaged fiber photographed in polarized light with the fiber in the extinction position. The birefringence of cellulose microfibrils permits the disalignment of the microfibrillar structure to be observed as light and dark areas

The contrast with the damage tracheids, which dispersed extremely rapidly, is very marked. In tracheids such as this, the damage is not local, or restricted to a number of places along the wall. If it were the tracheids would break up into a number of segments. Rather, the whole wall is affected.

The effect of axial compression on wood fibers, therefore, is to disarrange the cellulose microfibrillar structure. An acidic cooking liquor enters the structure and hydrolyzes glycosidic bonds in the cellulose molecule, breaking the chains periodically but not so frequently that water soluble products are formed. The increased rate of chain cleavage when the microfibrils are disarranged may be due either to an increased surface area and accessibility of the cellulose chains to the hydrogen ion, or to an increased reactivity of the glycosidic bond due to strain induced by the deformation. The reduction in cellulose chain length, probably in both the S_1 and S_2 layers of the wall, reduces the physical strength of the wall and it readily breaks up into fragments in the beater.

POSSIBILITIES FOR REHABILITATING DAMAGED WOOD

It would be extremely useful if wood which has been damaged could be treated in some way to make it less susceptible to hydrolytic degradation. This would require a method for reducing the accessible surface area of the cellulose molecules or removing the strain from the glycosidic bonds in the cellulose molecule. Both involve a movement of the cellulose molecule and a reduction in free energy. Three attempts were made to do this, one by alternate wetting and drying of the wood, another by warming in water for several hours, the third by swelling the wood in sodium hydroxide solution prior to the sulfite cook. None of these processes had any useful effect. It is possible that modifications of these methods or entirely different ones would lead to success, but at the moment it appears that prevention of damage is better than cure.

FUTURE WORK

An improvement in chipper design, based on principles already known and on a careful analysis of the strains induced in wood under various conditions of subdivision, would seem to be of immediate interest.

A rapid method for estimating quantitatively the amount of damage in a given wood supply would be useful not only in the mills but also in laboratory studies and in chipper design.

The effect of damaged wood on the quality of specific products such as corrugating medium, dissolving pulp, etc., should be studied.

The relative degrading effect of hydrogen ion concentrations throughout the sulfite pulping range is under investigation.

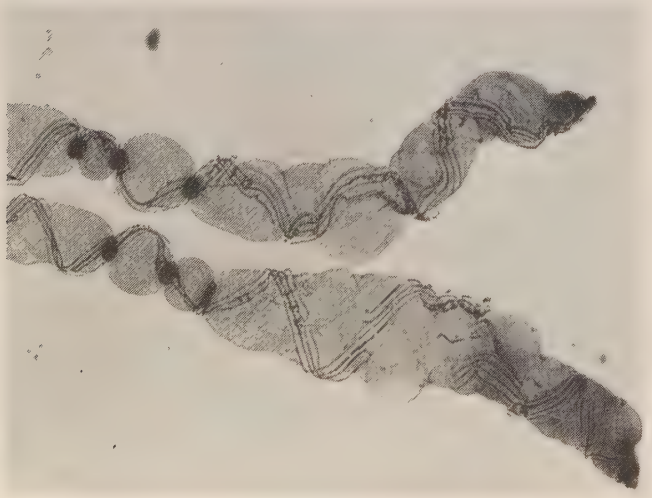


Fig. 15. Ballooning of undamaged fibers when treated with 0.2 M CED

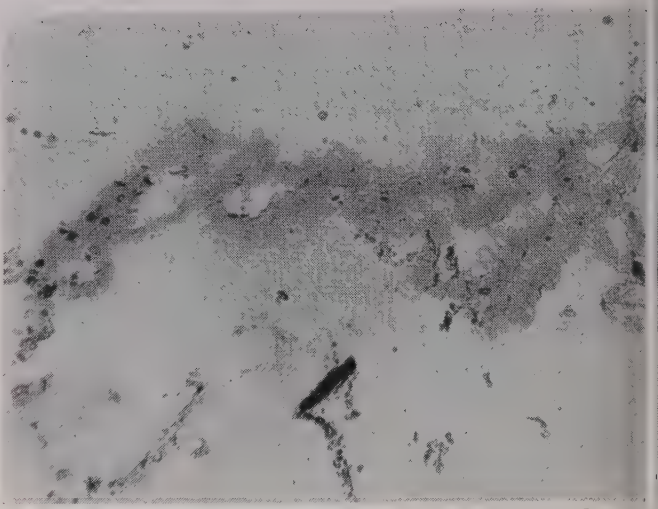


Fig. 16. Dispersing of damaged fibers when treated with 0.2 M CED

Further work could be carried out on chemical or other aids to wood disintegration prior to cooking. Thus, relatively large pieces of wood might be treated with, for example, sodium hydroxide, and then subdivided or fiberized without causing the cell wall dislocations which lead to acid susceptibility.

Considerable effort is being expended on genetic, silvicultural, and other studies with the aim of improving wood quality from the papermaker's viewpoint. Having grown a tree containing fibers of intrinsically high quality, it seems particularly worth while to study methods for avoiding needless mechanical degradation between stump and blow-pit.

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The Norman Chipper—Theory and Practice

E. L. CROWLEY and N. P. WARDWELL

An outline is given of the theory of chipping in general. It shows that, if the forces brought to bear on a log in a chipper are guided correctly, they will produce uniform, clean-cut chips. The troubles that are brought about by deviation from this pattern are listed. The facts led to the development of the Norman chipper which fulfills the necessary requirements. Chip analyses of samples from Norman chippers are compared favorably with standard chippers in two charts. A suggestion is made to improve the feeding of chippers to allow Normans and others to realize their full potential. Sawdust and power savings and improvement in pulp strength are also discussed.

The Norman chipper takes its name from a Norwegian engineer, Sigurd Norman, who came to this country in 1923 with a valuable background of experience in Scandinavian pulp mills. He worked with Rice Barton & Fales for a few years, and while there he designed a chipper which was a venture in a new field for them.

This chipper had six knives at a time when most makers thought four knives was the maximum workable number. People used to think that if a situation existed in which two knives could be in simultaneous contact with a log, then the log would be prevented from moving in. It was a situation to be avoided. But Norman *approached* this break-through even in those early days.

After leaving Rice Barton, Mr. Norman spent some time in pulp mills in South America. Then he joined the engineering staff of the Sumner Iron Works in Everett, Wash.

During all these years the theory of the Norman chipper was taking shape in his inquiring and creative mind. In December, 1939, a patent was issued to him. It is regrettable that the war and a little matter of horse trading held up the building of these chippers. It was not till the early 50's that they came on the market.

In most cases the Norman chipper has been outstandingly successful. The best results were obtained at first on the smaller units because the knives could be put closer together. The smaller logs and slabs put less strain on the weakest steel sections between the knives near the hub. Then later experience showed that it was safe to incorporate this feature of design in the larger units as well.

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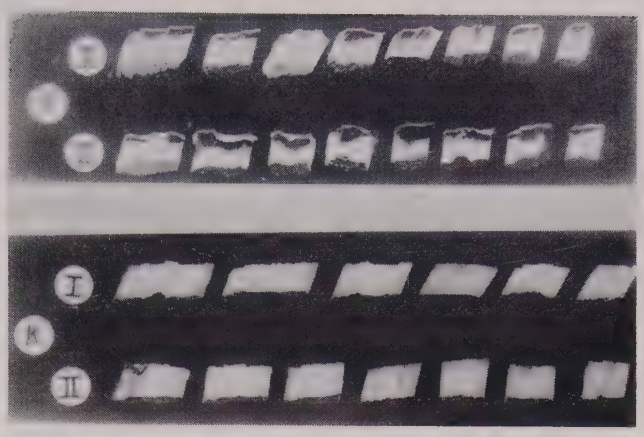

Fig. 1. Bruised and unbruised chips

The following discussion is intended to bring out the theory of chipping in general and to show that the Norman principle fulfills the requirements that must be met if a chipper is to produce the best possible results.

THEORY OF CHIPPING

The length of the chip, the angle at which it is cut, the amount of bruising, and the cleanness of cut, are all variables which a chipper is designed to control. Recent pulping developments stress the need for thin chips. Card breakers do break up the chips parallel to the grain in what might be called the width dimension. Norman chippers do seem to produce thinner chips than standard. But we are not including the control of these dimensions in our discussion because it is considerably less positive than the control of the chip length.

At one time it was thought that a chipper depended upon gravity to bring the wood into contact with the disk between cuts. However, it is now acknowledged that the logs are pulled in against the disk by the knives. This is illustrated by the operation of the horizontal feed chipper where the log is moved only by the pull-in action of the knife. But our subject involves only *gravity* feed machines.

As the knife slices through the log, the cut face of the log follows the adjacent knife surface as far as possible. The object is to pull the log toward the face of the disk so that just at the time it reaches the next chip slot, it is ready for another cut.

The angle formed between the vertical line and the adjacent knife surface, we at Carthage Machine call the "pull-in" angle. The correct name for this angle is actually the "rake" or "clearance angle" of the knife. However this angle plays such an important part in pulling the log into the disk that we keep to the name "pull-in angle."

It is very important to get this angle right. Too large an angle causes some troubles, and too small an angle causes others. We are listing some of these troubles herewith.

"Pull In" Angle Too Large

1. The wood is forced against the face of the chipper causing extra wear, especially at the outside end of the knife. Longer chips are cut at the worn spots.

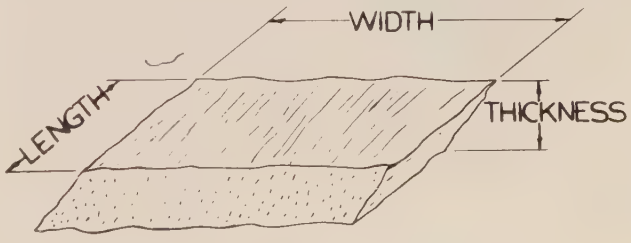

Fig. 2. Orientation of chip dimensions

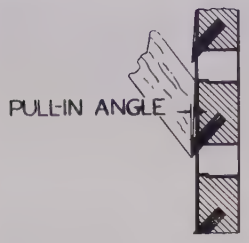

Fig. 3. Pull-in angle correct

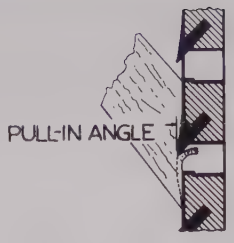

Fig. 4. Pull-in angle too large

2. The knife pulling the log in hard against the disk surface, sets up forces that put a severe strain on the chips. This results in bruised and compressed fibers, rough chips, and sawdust.

3. This strain is also transmitted to the log so that it is wrenched into a tipped-up position, and the knives cut a progressively shorter chip as they proceed into the log.

4. If small logs are pulled in too soon, there is a tendency for them to bounce away before the next knife can make contact.

"Pull-In" Angle Too Small

1. The log will not be pulled in far enough and a large percentage of shorter chips will result.

2. If the "pull-in angle" is zero, the knife will resist the pull-in, because the trailing edge of the knife is too high to allow the log to slide in toward the disk until the knife has completely disengaged itself. Sometimes the tip of the knife wears until the "pull-in" angle approaches this condition with zero value. Then the logs cease to move inward toward the disk. We have all seen logs whose ends have been actually burned by such knives rubbing but not cutting.

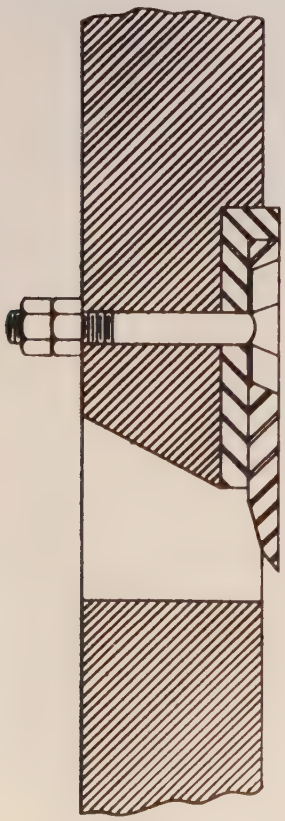

Fig. 5. Experiment illustrating zero pull-in angle

Years ago we tried an experiment with an 88-in. four-knife chipper with surface knives. We mounted the knives in almost the usual position except parallel with the disk surface, pull-in angle zero. They not only failed to pull the wood in, but the knives overheated enough to produce smoke and the temper was spoiled in about 10 min. That is what happens to a lesser extent with too small a "pull-in" angle.

3. Sometimes the knife tip wears enough so that there is a negative pulling effect. Then the logs or at least the short stub ends go flying back up the chute. We have heard of a number of injuries caused by this bad condition. It happens especially in cold weather or with very hard wood or when abrasive material is introduced.

We have seen that the "pull-in" angle can be neither too large nor too small. It must be just right or nearly so to get the best effect and avoid these troubles. It is desirable to make the "pull-in" angle as large as possible to avoid the evils of having this angle too *small*. In order to do this the knives must be close enough together to avoid the evils of too large an angle. Setting the knives for a shorter chip reduces the pull-in angle. So when making short chips it is especially important to have the knives close together. In large chippers the knives at the outside are far apart in spite of our best efforts to keep them close. So in these sizes it is still more important to have the knives as close together as possible. We do this by increasing the number of knives and mounting them as near the hub as we can with safety.

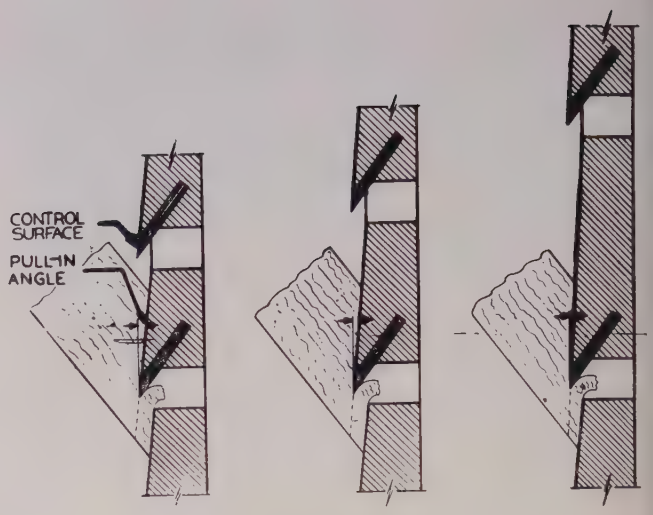

Fig. 6. Norman chipper pull-in angle decreases as knives get farther apart

NORMAN CHIPPERS

The above explanation leads to the conclusion that the "control surface" of the knife (see sketch arrow) must aim at the leading edge of the next chip slot for best results.

In order to fulfill this requirement, the Norman principle provides a variable "pull-in" angle. In this way as the distance between knives increases from inside to outside, the pull-in angle decreases accordingly. The control surface is aimed correctly at the next chip slot at every successive point along the knife edge.

We can illustrate this point by what sometimes happens in a standard chipper. Many operators of standard chippers have inadvertently made the "pull-in" angle too large and found that the wood bounces back a little. If they correct this and aim close to the mid-point of the next chip slot, the logs feed much better. That is the Norman principle

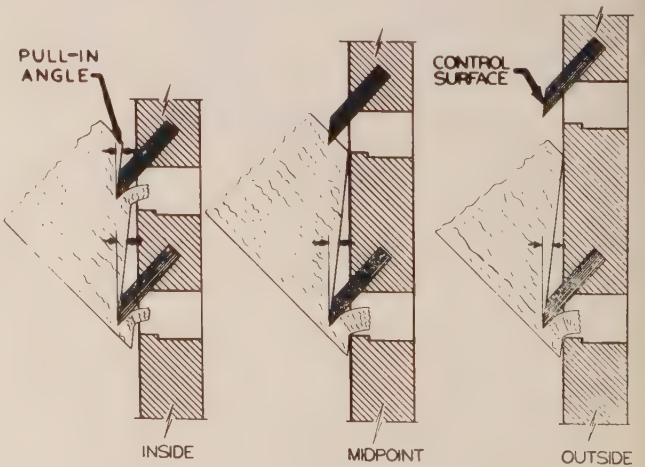

Fig. 7. Pull-in angle—too small—just right—too large Note short chips in left view.

acting at just one point on the knife edge. Outside this point the knives are pulling in too fast and inside not fast enough. But the Norman chipper uses this principle the full width of the knife. Every element of the control surface is aimed correctly.

Experience has shown that a pull-in angle of less than 2° is undesirable. It has been proved that best results in chipping occur in a Norman chipper when the pull-in angle varies from 4° at the inner end of the knife to 2° at the outside end of the knife. This means that the knives must be close together.

The helicoidal surface between the knives is a continuation of the varied "control surface" on the knives. This helicoidal surface acts as a guide for the face of the log and is especially important when small wood is being cut.

Theoretically it should be possible to cut uniform chips with a helicoidally ground knife without this intervening surface. To our knowledge the helicoidal knife alone has never been successful. We do know of one specific case in which it was not.

In the Norman chipper the knife moves through the log in the direction in which it is aiming; so it cuts cleanly. In the standard chipper by contrast when the log's downward movement is stopped, the knife has a scraping action that makes rough chips and sawdust. The Norman chipper design is geometrically correct. The results of operations using this chipper have proved the theory.

NORMAN CHIPPER PRACTICE

Chip Uniformity

This is the first point to be considered in any evaluation of a chipper operation. The more uniform the chip, the higher the concentration of chips in one size category. In Fig. 8 we have taken several analyses of samples from Norman and standard chippers and shown the percentage of chips in the category with the highest concentration in each analysis.

The chippers selected for these tests were all good installations and they were all in good condition. The 14 Norman samples were taken from 10 chippers. The nine standard samples were taken from five chippers. In general, you can see the trend that chip uniformity in the Norman chips is considerably higher than in the standard chips.

The standard chippers that show the highest percentages on this chart are the ones with very light loads where one log can be set in the spout with deliberate care. That introduces another variable which distorts the comparison because most of the Norman chippers are operated with fairly heavy loads.

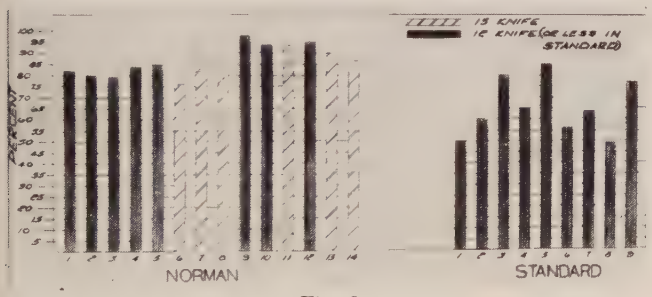

Fig. 8

A chipper with a feed spout full of logs makes a higher percentage of long chips than one with just one or two logs at a time. This is illustrated in Fig. 9. The solid line shows percentages of various chip lengths made while chipping one log at a time. The dotted line represents an analysis of chips made with the spout full. Notice that the dotted full-spout line shows a lower percentage of short chips and higher percentage of long chips.

This leads to a thought that applies to all chippers whether Standard or Norman. A poor feed can spoil the operation of a good machine.

Chipper Feed

The objectives of this optimum feed design are twofold; first to even out pile-ups of logs on the conveyor, and second to provide a chute that will stabilize the logs as they slide down to the chipper disk.

The first is attained by running the conveyor at high speed just a little slower than the feeding speed of the chipper. For a 96-in. chipper with 15 knives cutting $^5/_8$-in. chips at 400 r.p.m. giving a feed speed of 312 f.p.m. a conveyor speed of 300 f.p.m. would be good.

But the high speed conveyor brings up the problem of logs flying through the air and hitting the chipper disk before becoming stabilized in the feed spout. Figure 10 shows our recommendation for such a chute to conform roughly to the trajectory of the log traveling at that speed. It must be high enough so that the feed chute is tangent to the last part of the arc. We think this is probably the best solution to this problem, we have yet seen.

Uniformity

A report from one mill after the conventional 10-knife chipper was replaced by a 15-knife Norman chipper says they used to have two to three digesters a day of undercooked

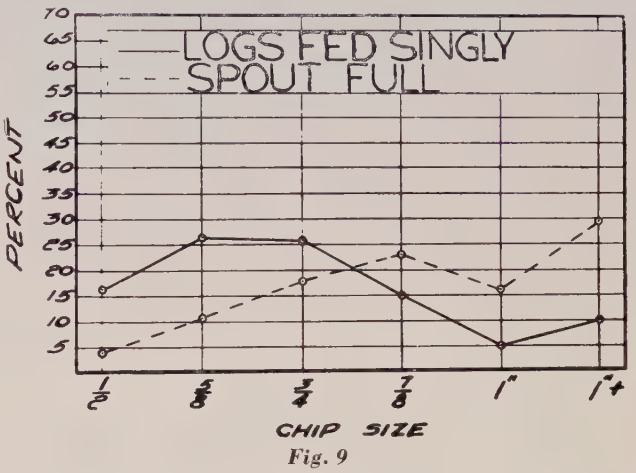

Fig. 9

chips returned from the knotters. Now this is reduced to one per day. The knotters no longer plug as they formerly did. Chips flow better from the chip bin because there are no longer any long strings or ribbons.

Another mill says they have saved a large sum of money in labor cost by freeing up jams caused by oversized chips in conveyors.

Sawdust

This is a waste product for which it is almost impossible to make a fair comparison from mill to mill. The quality of care of the knives alone is a variable that is hard to eliminate. We have many chip analyses of Norman chips with sawdust content less than $^1/_2$%. We also have some for standard chippers just about as low.

But when chip samples are taken before and after the installation of a Norman or from a standard and a Norman in the same mill, many variables are eliminated. In practically every case Norman chippers show a good saving. The operator of one such mill advised us of a saving of from $^3/_4$ to 1% of the wood chipped since installing a Norman disk.

Another mill ran tests weighing sawdust from about 2000 cords chipped on each type of chipper. Both showed good results, 0.495% for the Norman and 0.695% for the standard. This same mill also showed lower sawdust for the Norman on daily Williams Classifier tests over a period of 17 weeks. With only one exception the Norman was better in every week. The final average was 0.45% for the Norman and 0.94% for the standard.

These samples are typical where fair comparisons like this are possible.

In cold weather, chips break up more finely. The "pull-

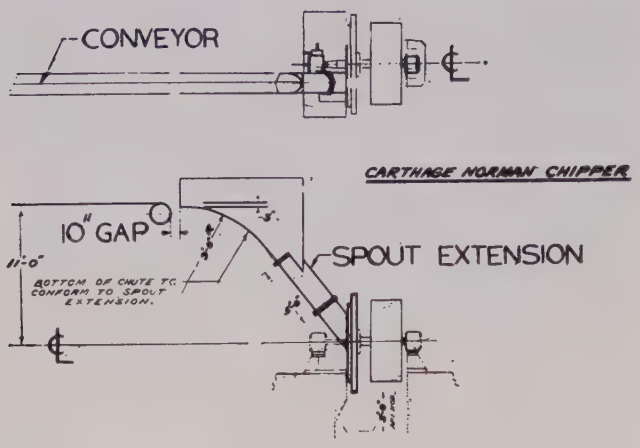

Fig. 10

in" angle must be greater under these conditions to prevent the troubles described in the theory part of this paper. In order to do this without causing other troubles the knife must be adjusted out farther and a setting for a longer chip must be used. When warm weather returns the "pull-in" angle as well as the chip length should be restored to the original dimensions. For winter operation if a longer chip is undesirable, the "pull-in" angle can be increased within limits without changing the chip length. But that brings on the evils of too large pull-in as described above.

In one mill with a large Norman chipper, it was necessary to change knives every 2 or 3 hr. because of using the wrong grind angle. When this angle was corrected, they were able to chip as long as 21 hr. and cut over 1000 cords of hard wood before changing. The outdoor temperature was −32° F.

Pulp Quality

George Tomlinson of Howard Smith Paper Mills, Ltd., made a statement on this subject in his paper on Magnefite pulp in January, 1958. Magnefite pulp made from hardwood chips from a standard chipper had strength slightly lower than comparable sulfite pulps made from spruce chips from the same chipper. But when the hardwood chips were cut on a Norman chipper the Magnefite pulp was slightly stronger than the sulfite. This strength was still higher with chips cut on their laboratory guillotine. This was the result of less chip bruising.

He also showed in a table that chip damage caused a marked reduction in strength of Magnefite and sulfite pulp. But it had relatively little effect on the strength of sulfate or neutral sulfite pulps.

Power

Theoretically, the Norman chipper should take less power. The force required to pull the log against the resistance of the disk is eliminated. Unfortunately, we have never been able to run any exhaustive tests to prove our theory of less power consumption in a Norman chipper.

Four Norman chippers with 15 knives have replaced four 10-knife Chippers and are now operating satisfactorily with the same motors that had been running the 10-knife chippers. Three of these mills reported the swings of the ammeter were reduced very considerably by the Norman design. One said the peak was $^1/_3$ less than its former size. Another with 12 knives reports about the same. None of these installations had been overpowered.

An engineer would say these reductions can partly be accounted for by the increased flywheel effect of the new chipper installations as compared with the old. For any given installation powered by wound rotor motors, peak loads can be smoothed out by addition of WR^2.

However, it does show that with proper adjustments in the speed and flywheel, the change to 15 knives can be accomplished in many cases with the old motor.

We have tried it once with a synchronous motor drive with no ill effect, changing from a 10-knife standard to a 12-knife Norman, but there was probably ample margin in that case anyway.

The evidence we have assembled shows the trend of results definitely favorable to the Norman design. We feel sure that if more of these mills had chip sampling devices and sawdust weighers like those made in Park Falls, Wis., this evidence would be even stronger.

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New Chipper Design Features and Their Effect on Cooking Yields

R. M. BUECHLER, L. L. DUNCAN, and J. R. HALLER

In order to reduce sawdust, slivers, and oversize chips to an absolute minimum, the D. J. Murray Manufacturing Co. has developed a new chipper into which has been incorporated the offset v-type spout, the Uni-Chip helicoidal surface, and machines having up to fifteen knives. The offset "v" supports the log so that there is no fish-tailing or bouncing. The Uni-Chip helicoidal surface gives a much more uniform chip than the standard disk face, considerably less bruising of the chip resulting in less sawdust, wearplates and knive covers last three to four times as long with Uni-Chip than with the standard chipper face, and because of a more uniform chip a greater yield can be obtained from the cook.

Up to the last several years, there had been very little research and development work done in regards to this mechanical operation of making pulp mill chips from round sticks of wood. A modern pulpwood chipper is no longer a glorified hog used to make small pieces from a single large stick. It is now a precision built and operated piece of machinery, and in order to obtain maximum value from this expensive machine, it must be maintained in the best possible manner.

Making chips in a pulp mill is somewhat different than other ends of the papermaking process because once the chip has been cut, there is absolutely nothing that can be done to alter the chip to increase yield. increase fiber strength, or decrease the amount of sawdust. On the paper machine, if a mistake is made in furnish or basis weight, the paper becomes broke and is sent back into the system and repulped. This is not true of a chip. This is very much analogous to the difference between producing a movie and producing a legitimate stage play. In producing a movie, it is possible to retake the scene and cut as is necessary to come up with a perfect production. However, in any particular performance of a legitimate stage play, once the action has taken place or the words spoken, there is nothing that can be done to alter what has gone before. The

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chipping operation, therefore, is very similar to this production of the legitimate stage play.

Now let's get a little more to the point, and determine what a good chip might mean in economics to any mill. As an example, let us take a mill processing 500 cores of wood per day on a 300 working day per year basis and paying $18 per cord. It can be seen by simple multiplication, that the mill's total wood cost is $2,700,000. Each 1% of sawdust produced costs the mill $27,000 a year. Therefore, without resorting to any complicated mental gymnastics, a decrease of from 5% sawdust down to, say, 2% sawdust results in savings to the mill of $81,000.

The presence of slivers and oversize chips results in either overcooking or undercooking in the digester, and directly affects the yield obtained per cord of wood. Therefore, whenever one talks about sawdust, slivers, or oversize chips, he automatically talks about cooking yields. Therefore, it behooves the operators to cut the best chip possible, which automatically keeps to a minimum the amount of sawdust, slivers and oversize chips.

Now that we have some idea of what we would like to do in the way of cutting chips, let's now talk about the new features in chipper design and construction that tend toward the ideal situation, which is, of course, to produce 100% of cut chips within the length category required without sawdust, without slivers, and without oversize. The authors will attempt to be as objective as possible in discussion of these new design features, but admittedly will be discussing the new MURCO chipper.

Let's follow the stick as it leaves the conveyor feeding the chipper. Originally we had only a v bottom with equilateral sides. This became a holder for the stick so that the stick would have no chance to revolve or bounce. As can be seen, by having a v bottom, a stick of any diameter would be positioned in place as it slid down the spout. This was part of the answer to improved chip quality. However, in our new chipper we have gone a step further and incorporated the offset v.

In order to fully understand our reason for incorporating the offset v into the chipper spout, we must consider the multiknife action on the stick of wood. I believe that all of us have been aware for years that two knives cutting in a stick of wood simultaneously produced better chips and prevented bouncing. This was not possible in chippers in which only one cut at a time was made, regardless of stick size. The purpose of the offset v, therefore, is to allow sticks of smaller diameters to be held in closer to the hub of the disk, thus producing more multiknife cuts in smaller diameter sticks.

We now have the stick properly held in the offset v spout. Now let's cut it with knives mounted on the most modern chipper disk available. I believe that all chipper manufacturers agree, as well as most operators, that some form of a helicoidal surface on the disk is necessary, particularly with ten knives or more, to keep at a minimum such things as chip bruising, sawdust, and variance in chip length. The MURCO trade name for a helicoidal disk surface is "Uni-Chip."

The Uni-Chip arrangement in the MURCO chipper utilizes standard straight knives, no warping or twisting required, and standard grinding procedures are used. We use our standard type knife holding device. The knife covers are machined in two planes, while the wearplates following the knife cover are installed in a third plane. By so doing, we accomplish a modified helicoidal surface which allows the log to feed in gradually and gives much better support to the log, preventing bruising and subsequent production of sawdust.

Going hand in hand with the offset v-type spout and the Uni-Chip is an increased number of knives in the disk. As most of us can recall, the original pulpwood chippers were slow speed, four-knife machines. Then, with the advent of the multiknife patent, came the increase to 10 and 12-knife disks. At the same time that the number of knives was increasing, the revolutions per minute of the disk were increasing also. This led us to believe that even though chip quality continually increased with the number of knives, it also increased with the speed of the disk.

However, as the number of knives increased in the disk, the rate of drop between knives from the inside toward the hub to the outside toward the periphery of the knife greatly aggravated the problem of bruising the chips and producing sawdust. It became imperative that some form of helicoidal surface be applied to the disk to insure proper distribution of unit pressures between the log and the disk at the time of cutting to prevent serious bruising and subsequent production of sawdust.

Here are a couple of letters indicating the results of the helicoidal Uni-Chip surface as applied to a standard chipper disk. "In answer to your letter regarding the Uni-Chip conversion, the chip classification shows that we have fewer oversize chips, which results in better cooking yield in the digesters. We also have more uniformity of chips in the $^5/_8$-in. range, which is the chip size that we require." Here is another testimonial indicating improvement of wearplate service life. "We noted, by using the Uni-Chip parts, there is a very sharp reduction of wearplate wear. With the old arrangement, it was necessary to change wearplates every 6 weeks to 2 months. With the Uni-Chip parts, it has not been necessary to change a wearplate in over 7 months." Quite obviously, the wear on the disk was caused by the rubbing of the wood and, of course, any abrasion such as this contributes to the production of sawdust.

In summary, Uni-Chip helicoidal surface gives the following results:

1. A much more uniform chip than the standard face disk.
2. Considerably less bruising of the chip, resulting in considerably less sawdust.
3. Wearplates and knife covers that will last three or four times as long with Uni-Chip than with the standard chipper face.
4. Because of a more uniform chip, a greater yield can be obtained from the cook.

Now let us suppose that you have bought a brand new chipper of the latest design. What features are incorporated that will allow you to maintain it properly so that it will always be in the best possible condition? First, the spout bed knife. Again, in order to keep slivers and sawdust to an absolute minimum, these bed knives must be kept sharp and square. The bed knives on the new MURCO chipper are withdrawn from the back. Being light in weight, "fetch and carry" is no problem. Item two is the knife seat insert. The terrific impact of the cutting action forces the chips against the portion of the knife seat directly behind the knife. This small area is subjected to terrific eroding forces. The deep knife seat inserts in the new MURCO chipper are installed that they can be easily changed to prevent the erosion that ultimately produces sawdust. Item three is the knife covers and wearplates. We have incorporated into the Uni-Chip type of chipper disk, our standard knife mounting which allows replacement of the knife cover and the wearplates very easily. The knife covers are replaced by simply backing off the nuts on the knife holding bolts and pulling the cover away. The wearplates are replaced simply by backing off the nuts on the wearplate bolts and removing the wearplates. The Uni-Chip wearplate is simply a flat steel plate, and since it is not a complicated part, its replacement cost is low. The incline surface on which the Uni-Chip wearplate rests is machined at the factory and is not subject to wear.

The fourth and equally vital point is the disk knives. These must be kept sharp and properly ground to angles recommended by the chipper manufacturer for best results.

Recognizing that vital parts of the disk—when subject to rapid wear—are directly responsible for a deteriorated chip and an increased amount of slivers and sawdust, we developed a hard surfacing process which extends considerably the wear

life of these critical parts; namely, wearplates, knife covers, and knife seat inserts. The hard surfacing application is called Murcote, and the results from it in typical installations have been surprising. For instance, here is a case where Murcote resulted in three to four times the wear life as contrasted to ordinary abrasion resistant steel plates. Again, we offer this feature as a method to insure keeping the chipper in its best condition for producing the best chip possible.

To sum up in very short order what has been discussed is the fact that we have developed the v-type spout to prevent fish-tailing of the log, thus preventing a great portion of oversize chips. Furthermore, we have added the feature of the offset v-spout, together with 15 knives, to insure multiknife chipper action on the smallest diameter stick possible, thus increasing chip quality, and, thirdly, the application of the Uni-Chip or the modified helicoidal surface to insure constant feeding of the wood and lower unit pressures between the wood and the chip to prevent bruising and to cut sawdust to a minimum. And, fourth but not least, an attempt has been made to impress upon you that the finest chipper made is no better than the maintenance given it after it has been installed and running.

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Bisulfite and Kraft Pulping of Saw Chips from Douglas-Fir and Southern Pine

N. SANYER, E. L. KELLER, and J. S. MARTIN

Saw chips for pulping experiments were produced by sawing wood cants with a 48-in. head saw at feed rates ranging from one-third to one-eighth of an inch per saw tooth. The wood fractions discarded on screening (largely the fraction passing through a screen with $^1/_{16}$- or $^1/_8$-in. holes) before cooking varied from 12 to 27% of the total material. Both Douglas-fir and southern pine were cooked by the kraft process. Douglas-fir was also cooked with sodium bisulfite, using a 4-hr. schedule that gave a pulp with a permanganate number close to 30 and generally negligible screening rejects. Increasing the feed rate of the saw to obtain longer saw chips benefited the strength of kraft pulps but not the strength of the bisulfite pulps over the range of $^1/_3$- to $^3/_{16}$-in. bite. Kraft pulps made from Douglas-fir saw chips at the largest bite had about 80% of the burst and tearing strength of reference pulps made from conventional chips. Bisulfite pulps from saw chips were considerably weaker than the control pulps, but much of the strength loss is attributed to damage to the wood by the stresses involved in sawing.

Saw chips promise to furnish a fresh new source of wood for the pulping industry, with one estimate placing the potential annual supply in the South alone as equivalent to 5.5 million cords of wood (*3*). The production of so-called saw kerf chips has been described several times in the journals and has been the subject of some research (*1–5, 9, 10*). Specific information on the properties of pulps made from this material, however, has heretofore been limited to a single publication (*11*). This paper covers the kraft pulping of southern pine and also compares kraft and sodium bisulfite pulps made from Douglas-fir saw chips with similar pulps made from conventional chips.

Over the years, the low strength of pulps made from sawdust and difficulties in pulping have effectively discouraged its use. Credit for the initiation of saw chipping, which provides wood particles of appreciably greater length in the fiber direction, is given to J. T. Griffin, Valdosta, Ga., who devised suitable saws and promoted their use. A number of sawmills have revised their operation as a consequence to produce saw chips for commercial pulping.

The term saw chips is applied to the coarse wood fragments that are obtained when logs or cants are fed to a saw at an unusually rapid rate of feed per saw tooth. After the finer material has been screened out, the chips contain a high percentage of particles that have a length in the fiber direction equivalent to the feed rate per tooth or to the "bite." Within limits, an increase in the feed rate will cause an increase in the length of the saw chip. Lengths of a quarter of an inch are typical. The number of uncut fibers is accordingly much greater than it is in ordinary sawdust. Simmonds and Hiller reported an average fiber length for a saw chip pulp of 85% of normal (*13*).

The production of saw chips is not without problems to the sawmill operator. Economically, much depends on further mechanical improvements as well as on relative price levels for lumber and chips. Several operators have reported substantial revenue from saw chipping, but in some instances, the daily output of lumber had to be reduced, because it was found that the new saws dissipated good lumber by cutting a wider kerf (*4*).

A study of some technical and economic aspects of saw chipping at the U. S. Forest Products Laboratory (*10*) disclosed considerable wander of the saw at times, as well as notably increased roughness of the wood surface. Both phenomena require sawing to greater oversize in order to secure boards with standard dressed dimensions.

The present pulping study covers a range in bite size of from $^1/_3$ to $^1/_8$ in. It includes cooking southern pine by the kraft process and Douglas-fir by both the kraft and the sodium bisulfite processes. Douglas-fir is of considerable interest because of its predominance as a saw wood on the West Coast. The cooking with an acidic liquor was included in order to compare saw chipping with conventional chipping in respect to chipper damage. Sodium bisulfite pulping was included because this resistant species pulps more readily with bisulfite than with acid sulfite liquors. In normal chipping, the compressive forces applied damage the wood, so that the increased hydrolytic attack by acidic liquors cause a loss in pulp strength, but the loss has little or no significance if alkaline liquors are used. Although bisulfite liquors are less acid than acid sulfite liquors, both have been found to give comparable strength losses for a given degree of chipper damage, presumably because of the higher cooking temperatures customarily used with bisulfite liquors (*7*).

EXPERIMENTAL

Preparation of Douglas-Fir Saw Chips

Wood for the first series of digestions was taken from a single, old growth, veneer grade log (wood A) grown in the Plumas National Forest in California. This Douglas-fir log was 8 ft. long and 38 in. diam. A cant 7 by 9 in., running the full length of the log, was cut from each quarter. A fifth cant of equal size was taken from the center, cut into sections, and distributed among the other cants which were subsequently sawed into boards. Clockwise, the four cants had respective specific gravities of 0.466, 0.455, 0.454, and 0.486, with corresponding growth rates in rings per inch of 27.7, 34.2, 23.7, and 28.3.

Material for the second series of digestions was prepared from a similar log (wood B) that was about 26 in. diam. A single large cant was cut from the center that was further reduced to five cants 6 by 8 in.

Saw chips for cooking were prepared by sawing the cants into boards somewhat larger than 1 in. in thickness. The bite was held constant while sawing any one cant, but the speed was readjusted between cants to furnish chips of the desired lengths. Feed rates for the four cants from the first

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Table I. Screen Classification[a] of Saw Chips Prepared at Various Bites per Sawtooth

Diameter of screen holes, Passing material through, in.	Retaining material, in.	Screening data on chips produced at- 1/8-In. bite, % [b]	1/4-In. bite, % [b]	3/16-In. bite, % [b]	1/8-In. bite, % [b]
		Douglas-firwood-A			
...	1	1.5	0.1	0.2	0.1
1	1/2	1.0	1.4	0.8	0.4
1/2	3/8	4.8	2.8	0.5	0.5
3/8	1/4	61.7	54.3	16.4	1.4
1/4	3/16	16.1	18.4	54.1	35.5
3/16	1/8	5.3	8.2	9.2	35.6
1/8	1/16	6.0	10.5	14.1	19.3
1/16	Tray	3.6	4.3	4.7	7.2
		100.0	100.0	100.0	100.0
3/8	1/8	83.1	80.9	79.7	72.5
		Southern Pine			
...	1	0.9	0.4	0.9	0.2
1	1/2	3.4	1.6	1.1	0.4
1/2	3/8	7.5	8.9	7.4	1.1
3/8	1/4	23.0	26.1	26.2	18.6
1/4	3/16	34.6	30.0	25.9	28.3
3/16	1/8	11.5	13.5	14.7	18.2
1/8	1/16	13.1	13.7	17.2	23.1
1/16	Tray	6.0	5.8	6.6	10.1
		100.0	100.0	100.0	100.0
3/8	1/16	82.3	83.3	84.1	88.3
3/8	1/8	69.1	69.6	66.8	65.2

[a] Williams oscillating classifier using screens with round openings; 13-min cycle.
[b] Per cent of total weight.

log were, clockwise, 1/3, 1/4, 3/16, and 1/8 in. per tooth. Cants from the second log were sawed at 1/3 and 3/16-in. bites.

The 48-in. saw used to make the chips was fitted with 12 style D inserted teeth that cut a 5/16-in. kerf. For the 7-in. cut at 1/3-in. bite, the saw removed solid wood equivalent to 83% of the gullet area of 2.8 sq. in. per tooth. Whether or not the 17% of free space was sufficient to avoid crushing of the saw chips was not determined, but the screen analysis data showed no conspicuous reduction in average particle size at maximum bite, such as would result from overcrowding the gullet.

The planed boards from each cant of the first log were converted to conventional chips 9/16 in. long with a 47-in. pulpwood chipper at the Laboratory. The feed spout on the chipper had been reduced in area by blocking in order to limit bounce and so improve the quality of the chips. Boards from the second log were converted to 1/3 and 3/16-in. chips, which corresponded to the nominal length of the saw chips made from the respective cants.

A sample of each lot of saw chips made from the first log was shaken for 13 min. in the Williams oscillating classifier. The remainder of each lot was screened in 2-min. cycles, retaining for pulping the fraction that passed through holes 3/8 in. diam. but was retained on the screen with 1/8-in. holes. The fraction taken from the 1/3-in. saw chips made from the second log was increased to include the material passing through 1/2-in. holes. The dryness of the saw chips varied from batch to batch between 68 and 77% when loaded into the digester.

The size classification data are given in Table I. The percentage of total material passing through holes 3/8 in. diam. but retained on 1/8-in. screen increased from 72.5% for wood sawed at 1/8-in. bite, through 79.7 and 80.9 for 3/16 and 1/4-in. bites, to 83.1% for the coarsest bite. The amount of fines decreased most between 1/8 and 3/16-in. bites.

Preparation of Southern Pine Saw Chips

The southern pine saw chips were made from a group of 10 logs chosen largely on the basis of size from a carload of slash, loblolly, and longleaf pine wood. A 7 by 9-in. cant was sawed from each log, which was about 10 in. diam. Each cant was cut into four sections of equal length, and a randomly selected section from each of the 10 logs provided the saw chips of a given bite size. The saw had 36 teeth instead of 12 but otherwise was similar to the one used to cut the Douglas-fir cants.

The material used for cooking included the fraction passing through 3/8-in. holes but retained on the screen with 1/16-in. round holes.

The size distribution of the southern pine saw chips (Table I) differed a good deal from that of the Douglas-fir saw chips, which may be attributed to a combination of partial drying of the southern pine logs before sawing and to differences in the wood itself. Compared on the same basis as the Douglas-fir fractions retained for cooking, such as the amount passing through 3/8-in. but retained on 1/8-in. holes, the quantity of accepted southern pine saw chips was more uniform but considerably less. Since the narrow and pin-shaped chips may pass through the screen holes endwise, the difference between the classification of these woods does not necessarily indicate true distribution of particle length but rather the degree of splitting of chips.

Table II. Cooking Conditions[a] Used in Sodium Bisulfite Pulping of Douglas-Fir

Cant no.	Type of chip	Nominal length of chip, in.	Total sulfur dioxide charged,[b] %	Time at 170°C., hr.:min.	Maximum digester pressure,[c] p.s.i.	Spent liquor Reducibles calculated as sulfur dioxide, g.p.l.	pH[d]	Yield[b] Screenings, %	Yield[b] Total, %	Permanganate number
					Wood A					
1	Normal	9/16	30.0	2:33	150	2.3	2.20	2.2	50.7	31.0
	Saw	1/3	30.1	2:25	150	15.2	2.72	0.0	52.0	39.9
2	Normal	9/16	29.7	2:40	150	8.5	2.29	0.9	50.8	31.9
	Saw	1/4	27.1[e]	2:35	140	10.1	2.39	0.0	49.9	31.2
3	Normal	9/16	27.2[e]	2:32	118	2.1	2.41	0.6	52.9	31.1
	Normal	9/16	30.4	2:35	181	17.1	2.63	0.4	51.6	29.5
	Saw	3/16	29.9	2:25	150	17.8	2.78	0.0	52.9	30.3
4	Normal	9/16	27.0[e]	2:35	123	17.1	3.14	3.0	56.5	39.1
	Normal	9/16	30.1	2:48	150	11.1	2.31	1.8	53.0	31.2
	Saw	1/8	30.1	2:25	149	19.9	2.86	5.2	55.9	40.6
					Wood B					
...	Normal	1/3	30.0	2:30	150	14.5	2.55	0.1	50.9	25.0
	Saw	1/3	30.0	2:30	150	5.1	2.10	0	50.3	23.1
...	Normal	3/16	30.0	2:29	150	2.2	2.20	0	49.5	23.4
	Saw	3/16	29.7	2:29	150	2.1	2.20	0	49.9	24.5

[a] The digester is evacuated (water aspirator) for 10 min., liquor:wood ratio 6.5:1, 45 min. to maximum temperature.
[b] Moisture-free wood basis.
[c] Digester relieved when necessary to keep pressure from rising above 150 p.s.i., except one cook (cant No. 3).
[d] Low pH values indicate near or complete liquor decomposition.
[e] Liquor:wood ratio of 5.5:1.

Table III. Comparison of Douglas-Fir Bisulfite Pulps Prepared from Normal Chips and Saw Chips. Wood A

Cant No.	Type of chip	Nominal length of chip, in.	Properties of pulps[a]							
			Permanganate no.	Freeness (Canadian Standard) ml	Beating time, min.	Burst factor	Tear factor	Folding endurance (M.I.T.), double folds	Breaking length, m.	Sheet density, g. per cc.
1	Normal	9/16	31.0	500	21	52	88	260	8700	0.72
				300	27	56	76	380	9300	0.74
	Saw	1/8	39.9	500	10	25	51	10	6600	0.67
				300	14	27	45	22	7000	0.70
2	Normal	9/16	31.9	500	18	55	82	230	9000	0.69
				300	24	57	76	300	9100	0.72
	Saw	1/4	31.2	500	8	25	51	19	4800	0.68
				300	14	27	38	30	6000	0.74
3	Normal	9/16	29.5	500	18	59	91	250	9200	0.67
				300	26	65	82	300	9500	0.70
	Saw	3/16	30.3	500	8	24	58	24	6700	0.65
				300	13	27	52	34	7000	0.72
4	Normal	9/16	39.1	500	20	53	101	190	7600	0.61
				300	27	58	78	210	8800	0.65
	Saw	1/8	40.6	500	9	22	61	10	5900	0.61
				300	13	25	55	18	6600	0.66

[a] Interpolated beater test values. Test sheets conditioned and tested at 23°C. and 50% R.H.; nominal sheet weight of 60 g.s.m. moisture free.

Table IV. Comparison of Douglas-Fir Kraft Pulps Prepared from Normal Chips and Saw Chips. Wood A

Cant no.	Nominal length of chip, in.	Properties of pulps[a]							
		Permanganate no.	Freeness (Canadian Standard), ml.	Beating time, min.	Burst factor	Tear factor	Folding endurance (M.I.T.), double folds	Breaking length, m.	Sheet density, g. per cc.
					Normal Chips				
1 + 3	9/16	19.8	500	57	89	201	1310	11100	0.68
			300	75	92	181	1630	11100	0.72
					Saw Chips				
1	1/8	18.9	500	43	69	154	800	9800	0.69
			300	60	73	150	1160	10400	0.71
2	1/4	19.6	500	42	70	142	870	9700	0.69
			300	60	72	128	1120	10200	0.71
3	3/16	18.4	500	43	64	131	710	9600	0.69
			300	60	71	129	1020	9900	0.70
4	1/8	20.4	500	42	50	147	420	8600	0.67
			300	56	56	138	620	9200	0.70

[a] Interpolated beater test data. Test sheets conditioned and tested at 23°C. and 50% R.H.; nominal sheet weight of 60 g.s.m., moisture free.

Table V. Comparison of Southern Pine Kraft Pulps Prepared from Normal Chips and Saw Chips

Nominal length of chip, in.	Properties of pulp[a]							
	Permanganate no.	Beating time, min.	Freeness (Canadian Standard), ml.	Burst factor	Tear factor	Folding endurance (M.I.T.), double folds	Breaking length, m.	Sheet density, g. per cc.
				Normal Chips[b]				
/8	27.1	49	500	78	177	700	10,300	0.62
		63	300	84	161	790	10,400	0.64
				Saw Chips				
1/8	23.6	48	500	55	154	420	8,300	0.59
		60	300	61	147	460	8,900	0.63
1/4	25.6	47	500	54	136	480	7,700	0.59
		60	300	57	122	580	8,600	0.63
3/16	24.6	42	500	51	154	360	7,900	0.59
		55	300	55	130	410	8,500	0.64
1/8[c]	22.9	42	500	43	133	270	7,600	0.58
		56	300	52	116	430	7,900	0.63
1/8	28.0	38	500	48	128	260	7,900	0.61
		51	300	55	126	370	8,400	0.64

[a] Interpolated beater test data values. Test sheets conditioned and tested at 23°C. and 50% R.H.; nominal sheet weight of 60 g.s.m., moisture-free.
[b] Chips prepared with conventional chipper.
[c] Cooked at a liquor to wood ratio of 5 to 1 instead of 4 to 1.

The effect on pulp quality of accepting or rejecting the finer fractions was not investigated, but previously Martin cooked material that had been divided by a 3/16-in. screen. He found that the kraft pulp made from the finer fraction was from 85 to 55% as strong as that made from the coarser fraction, with the breaking length showing the least reduction and folding endurance the most (*11*).

Pulping

The bisulfite pulps were cooked in a stainless steel digester 0.8 cu. ft. in size that was equipped with an external heat exchanger and circulating pump as well as a steam jacket. The cooking liquor generally consisted of enough technical grade sodium bisulfite dissolved in water to give 30% of total sulfur dioxide on the weight of moisture-free wood at a

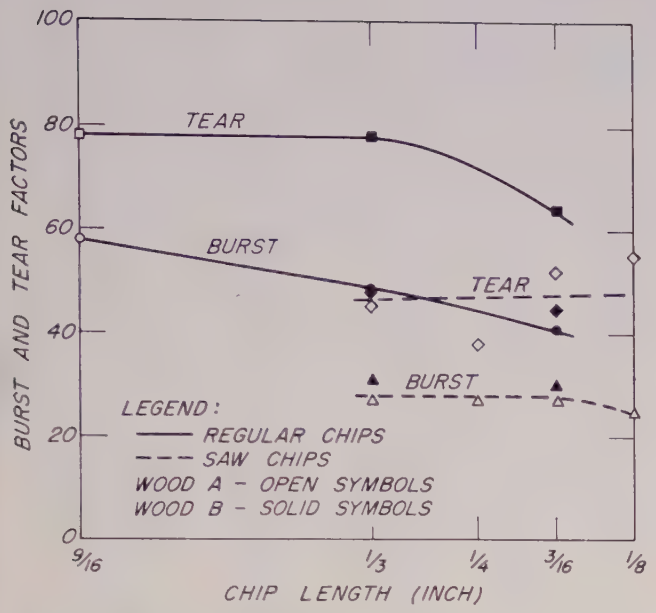

Fig. 1. Effect of chip length on burst and tear factors of Douglas-fir bisulfite pulps at 300-ml. freeness

liquor-to-wood ratio of 6.5 to 1 in the digester. According to the Palmrose method of analysis (*12*), the liquor contained almost exactly equal amounts of combined and free sulfur dioxide. The pH was close to 4.5 at room temperature.

The chips were exposed to a vacuum by means of water aspirators for 10 min. before admitting cooking liquor to the digester. After an increase to 170°C. in 45 min., this temperature was held for approximately 2.5 hr. with adjustments of a few minutes to secure pulps more nearly comparable in permanganate number. The digester was relieved only to keep the pressure from rising above 150 p.s.i. The content of total reducing substances in the spent liquor was measured by back-titrating a sample discharged into dilute acidified iodine solution and then calculating the grams per liter of sulfur dioxide from the amount of iodine consumed. Details of the individual digestions are included in Table II.

The kraft pulps were cooked in an 0.8 cu. ft., tumbling, jacketed digester, using a liquor of 25% sulfidity (active alkali basis). The time to reach the maximum temperature of 170°C. was 90 min., followed by 80 min. cooking at maximum temperature with Douglas-fir saw chips and short chipper

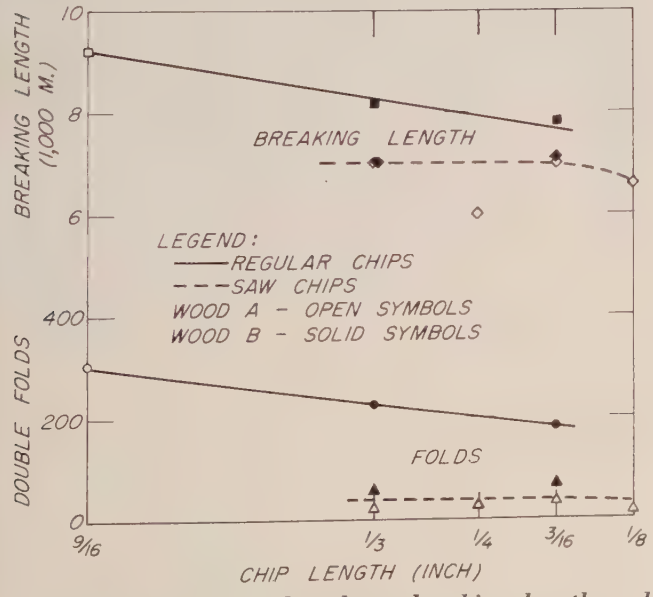

Fig. 2. Effect of chip length on breaking length and folding endurance of Douglas-fir bisulfite pulps at 300-ml. freeness

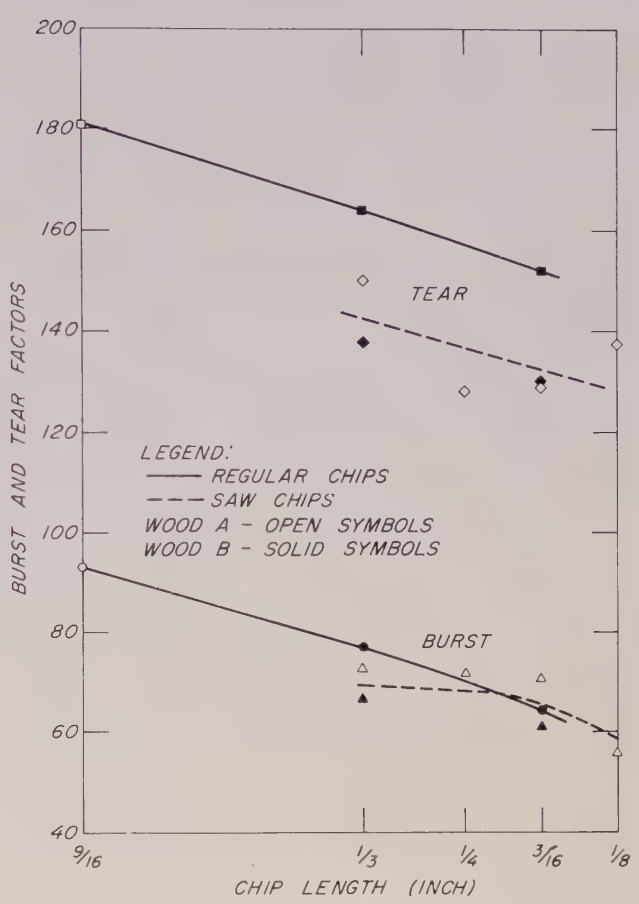

Fig. 3. Effect of chip length on burst and tear factors of Douglas-fir kraft pulps at 300-ml. freeness

chips or 90 min. with normal chips and all of the southern pine chips. The active alkali charge was 17.5% of Na_2O based on the dry wood for Douglas-fir, and 15.6% for pine. The ratio of liquor to wood was 4 to 1.

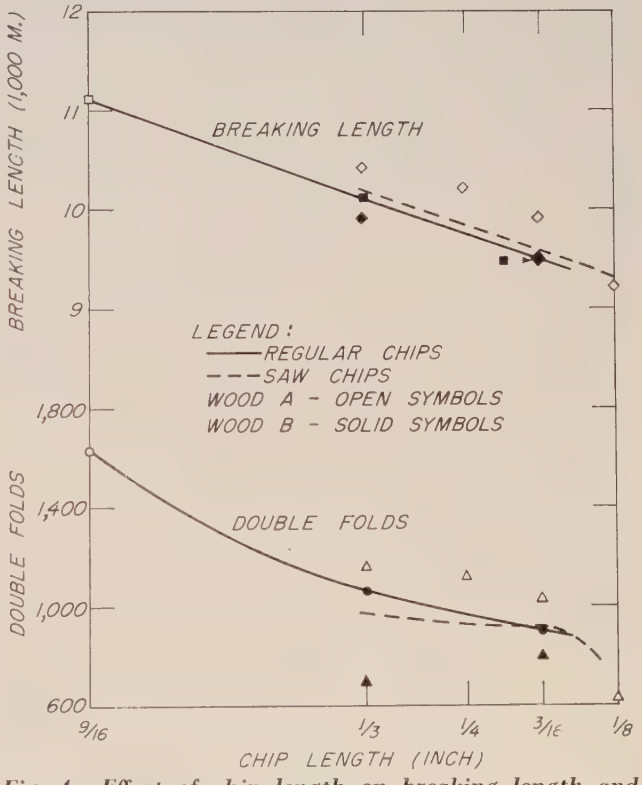

Fig. 4. Effect of chip length on breaking length and folding endurance of Douglas-fir kraft pulps at 300-ml. freeness

Table VI. Comparison of Douglas-Fir Pulps Made from Chipper and Saw Chips of Equal Nominal Length. WoodB

Type of chip	Nominal length of chip, in.	Properties of pulps[a] Permanganate no.	Freeness (Canadian Standard), ml.	Beating time, min.	Burst factor	Tear factor	Folding endurance (M.I.T.), double folds	Breaking length, m.	Sheet density, g. per cc.
				Sodium Bisulfite Pulps					
Chipper	1/3	25.0	500	16	45	86	210	7,900	0.69
			300	22	49	78	225	8,200	0.72
Saw	1/3	23.1	500	10	29	52	32	6,700	0.69
			300	14	31	48	53	7,000	0.72
Chipper	3/16	23.4	500	14	37	74	110	7,800	0.70
			300	20	41	64	180	7,800	0.73
Saw	3/16	24.5	500	9	27	52	40	6,500	0.70
			300	14	30	45	70	7,100	0.75
				Kraft Pulps					
Chipper	1/3	22.8	500	48	72	172	730	9,800	0.69
			300	68	77	164	1060	10,100	0.72
Saw	1/3	24.0	500	42	61	152	430	9,600	0.67
			300	60	67	138	690	9,900	0.70
Chipper	3/16	24.0	500	45	60	167	750	9,300	0.66
			300	64	64	152	900	9,500	0.69
Saw	3/16	22.3	500	42	57	142	525	9,400	0.66
			300	56	61	130	800	9,500	0.69

[a] Interpolated beater test values. Test sheets conditioned and tested at 23°C. and 50% R.H.; nominal sheet weight of 60 g.s.m., moisture free.

On completion of cooking by either process the free liquor was drained, the pressure was released, and the softened chips were dispersed at low consistency with a motor-driven stirrer. The pulp was drained on wire mesh, washed with hot soft water, and put through a vibrating flat screen fitted with 0.012-in. slots. The yield of screened pulp was determined by pressing, weighing the crumbed material, and sampling for moisture content.

The testing methods applied to the pulps followed the standard TAPPI methods. Where the reported permanganate number is more than 35, 50 ml. of potassium permanganate were applied with proportionate adjustment in the volumes of acid and water.

Because of the propensity that Douglas-fir has to decompose acid sulfite cooking liquors prematurely, some attention was given, as a matter of general interest, to the decomposition point in cooking with sodium bisulfite liquor. A digestion, using either saw chips or normal chips, was carried to the decomposition point using wood from each cant of the first log. The exact decomposition point was detected by means of a sight glass in the circulating system and blowdown was begun immediately. Previous work has shown that brief cooking beyond the decomposition point can cause a loss in pulp brightness but it does not appreciably affect either yield, strength, or permanganate number.

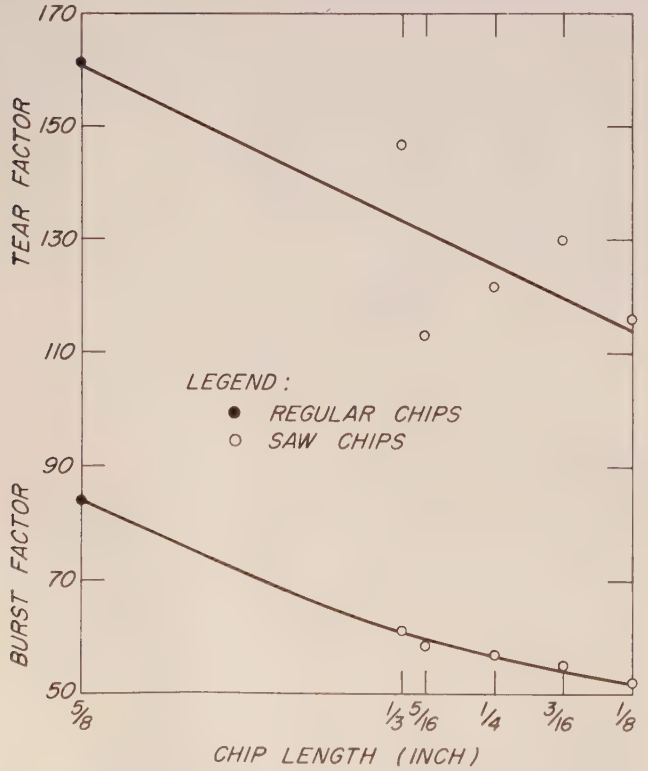

Fig. 5. Effect of chip length on tear and burst factors of southern pine kraft pulps at 300-ml. freeness

RESULTS AND DISCUSSIONS

Pulping

The bisulfite cooking cycle of less than 4 hr. from vacuum treatment to blowdown was short compared with the long times at low temperatures that have been suggested for the acid sulfite cooking of Douglas-fir. The permanganate number of 31 was high in relation to the range for traditional bleachable sulfite pulps, but this was satisfactory for the purpose of this study.

The amount of screening rejects in the saw chip pulps was

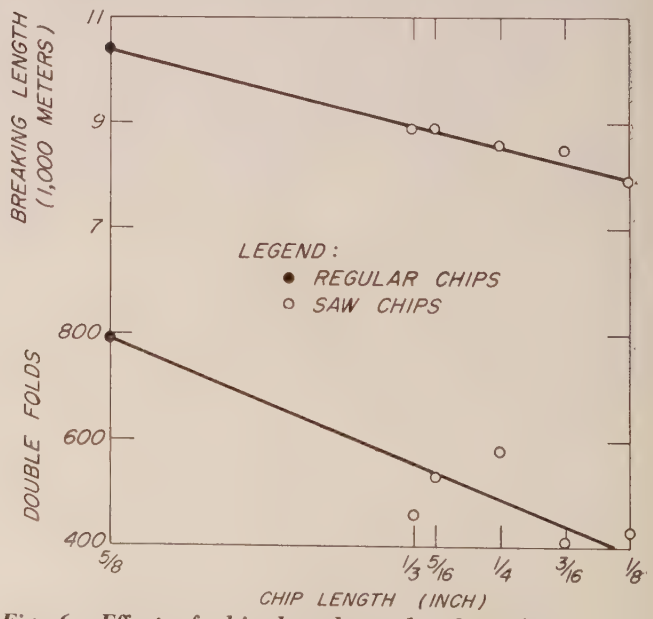

Fig. 6. Effect of chip length on breaking length and folding endurance of southern pine kraft pulps at 300-ml. freeness

negligible except for the pulp made from material prepared at 1/8-in. bite. This pulp contained screenings amounting to 5.2% of the weight of the original wood, and had a rather high permanganate number of 40.6. The reason for this exceptional behavior was not established, but contributing factors may include the fineness of the material, insofar as it impeded circulation, and an unusual concentration of extractives in the wood. The uneven distribution of extractives may also explain the lack of uniformity between the amounts of screenings in the pulps prepared from the normal chips.

In spite of the differences in growth rate and density between cants, and possible variations in the distribution of taxifolin in the log (*6*), decomposition was remarkably uniform at a permanganate number close to 31 (Table II). Since it is known that small amounts of quercetin react with large amounts of potassium permanganate (*8*), the residual lignin in the pulps may have been somewhat less than the test indicated. Chips from the second log were cooked to a permanganate number of 25 before the liquor decomposed, confirming that the decomposition point is not uniform from log to log.

Pulp Strength

The bisulfite pulps prepared from Douglas-fir saw chips were much weaker than the corresponding reference pulps made from normal chips (Table III). The saw-chip pulps had, on an average, 45% of the burst factor, 60% of the tear factor, 10% of the folding endurance, and 75% of the tensile strength of the control pulps. Contrary to what may be expected, the bite size was of no significance—at least at bites of 3/16 in. and longer (Figs. 1 and 2, dashed lines).

When cooked by the kraft process (Table IV), the 1/3-in. Douglas-fir saw chips had 80% of the bursting and tearing strength and 90% of the breaking length of the reference pulp. The 65% retention in folding endurance was especially good in comparison with the 5 to 10% retention achieved by the bisulfite process. There was evidence of a greater effect of bite size on strength (Figs. 3 and 4). The pattern followed by the southern pine pulps was essentially similar, except that there was no break below a length of 3/16 in. (Table V, Figs. 5 and 6).

From information of the comparative effect of chipper damage in cooking with acid and alkaline liquors, the smaller percentage of strength loss with kraft pulping as compared to bisulfite pulping was interpreted as evidence that coarse-feed sawing causes extensive failure of the woody structure. The relative damage arising from conventional and saw chipping was further investigated by making conventional chips with the chipper that were of the same nominal length as saw chips cut at bites of 1/3 and 3/16 in. Table VI and the solid points in the first four figures show that the bisulfite pulps from saw chips were still much weaker than the pulps made from the corresponding chipper-cut chips.

The proportionate reduction in beating time was much greater for bisulfite pulps than for kraft pulps. The acid susceptibility of cellulose in the cell wall apparently increases largely because of formation of failure planes in the protective layer of lignin or hemicellulose as a result of tension damage during saw chipping. This tends to weaken the fiber so that it swells and disintegrates more readily when beaten.

CONCLUSIONS

Particle length alone is not an adequate criterion in determining the quality of saw chips (nor is the fiber length of the resulting pulp).

In saw chipping, the mechanical damage to the wood and cell wall is greater than in regular chipping.

The kraft pulping is relatively insensitive to saw damage, but sulfite pulping gives a good estimate of this damage.

Further development of saws and sawing techniques may greatly benefit both sawmill and the pulping industries.

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Particular thanks to L. H. Reineke and H. Hallock, of the U. S. Forest Product staff, under whose supervision the saw chips used in these experiments were obtained.

DISCUSSION

CHAIRMAN CHILSON: Thank you very much, Dr. Sanyer. We appreciate your paper and the information which has been given to us as result of your work and that of your cohorts at the Laboratory.

We have purposely held off any discussion until after the papers because we have some additional people that have agreed to serve on the panel. Would Dr. W. J. Nolan and Dr. Wilfred Gallay now come up please? They have agreed to sit in on our panel.

We have heard about the influence of wood damage on pulp quality. We have heard about the improvements that have been made in the chippers to eliminate some of the wood damage. We have heard about the kind of pulp that can be produced from saw-kerf chips. I would like to open the session now for discussion.

N. P. WARDWELL: I wanted to ask Dr. Gallay something about his experience with making chips thin and the strength characteristics of the pulp obtained from making the chips thin, as compared perhaps to strength of pulp affected by chip damage.

W. GALLAY: In reply to Mr. Wardwell's question, it is my opinion that there are two factors to be considered. These are not necessarily independent and may in fact be related.

The first of these is the matter of the degree of penetration of the liquor into the chips. Thorough penetration is the basis of all cooking of wood, regardless of the nature of the cooking liquor. It is apparent that the dimensions of the chip are of primary importance in this regard. Generally, chip size is measured and reported as the area, i.e., involving the two larger dimensions only. We have shown that the length and width of the chip is of much less significance than the thickness. The latter is not measured in general because of the difficulties involved in rapid routine work.

Our results will be reported at the 1961 Summer Meeting of the Technical Section, Canadian Pulp & Paper Association. We hand sorted chips rather carefully into ranges of thickness, and then cooked each thickness range separately. Some work was also done on variations in area within one thickness range. It was quite obvious from this work that the thickness was of primary importance, and that the uniformity of the thickness was much more important than that of the area. In considering the thickness, due allowance must be paid to the corrugated nature of the surface in arriving at an average value.

The other factor is that of chipper damage. We have been able, by choosing an optimum thickness in chips made in a regular mill chipper, to obtain an improvement of the same order as that noted for special new chipper designs where it

is claimed that chipper damage is obviated. This requires explanation, since presumably we did suffer the usual chipper damage. It might be suggested that when thinner chips are produced on a regular chipper, the amount of chipper damage is actually reduced. This is, however, purely speculative.

I would also like to say a few words concerning the mechanism of the damage which is encountered in chipping. Dr. Stone has emphasized in his very fine piece of work that the molecular weight, as represented by the viscosity, of the cellulose itself is reduced. This is the large factor of change which he has found leading to poorer pulp quality. This is very interesting indeed, but the mechanism through which the viscosity is reduced is not immediately clear.

He has emphasized the action on the tracheids themselves, noting a buckling where compressive forces had been applied parallel to the grain, and he related this physical deformation directly to reduced viscosity of cellulose.

I wonder whether another aspect might not be taken into account. It is well known that pulp fibers of excellent quality are quickly ruined for papermaking by very brief exposure to the action of mineral acids at low concentrations. This is something we avoid whenever possible. If we now consider the middle lamella, consisting essentially of lignin, as relatively brittle in nature in response to an impact blow, it would appear that we have the probability of faults or cracks in this material, including locations adjacent to the fibers themselves. If this occurred, an opportunity would be presented for a direct attack on the cellulose by sulfurous acid, with consequent serious degradation effect on molecular weight and viscosity.

I suggest that the elucidation of the actual mechanism through which the damage by stressing is caused, be emphasized in further research. It has been amply proved that damage is done.

CHAIRMAN CHILSON: Thank you very much, Dr. Gallay.

BENGT RÅNBY (College of Forestry, Syracuse, N. Y.): I would like to comment about the mechanisms proposed for the chip damage. Two mechanisms have been proposed for the chip damage, and I would like to propose a third one.

We have known for a long time that it is not the degree of crystallinity which in itself protects the cellulose from hydrolysis, e.g., in a sulfite process. If we take cotton fibers and expose them to an acid sulfite process, we degrade the cellulose very badly under conditions which wood fiber cellulose (of lower degree of crystallinity) in the chip state can tolerate.

The reason for that is, I should think, rather clear. There are regions in the cotton cellulose fibrils which in spite of the high overall crystallinity of the fibrils are easily accessible to the hydrolysis. In these regions along the microfibrils there is some degree of disorder in the hydrogen bonding, which makes it easy or possible for the acid to attack right there. Native wood cellulose microfibrils have a lower overall crystallinity but apparently much fewer disordered regions.

I should like to describe one experiment before I go into the discussion. That is, if you take wood fibers which have been isolated as holocellulose by delignification and in which the hemicellulose is retained in the fibers, you can swell and deswell these fibers with water repeatedly and dry them out completely; and you hardly change the accessibility of the cellulose to acid by doing that.

But if you just mildly extract the hemicellulose out of the holocellulose fibers, and you hydrolyze the fibers after just one sequence of drying, the D.P. of the hydrolyzed cellulose drops sharply. These observations have been interpreted as follows. As long as the hemicellulose is left inside the fibers in its place, wetting and drying does not cause damage in the form of crushing of the framework, i.e., cellulose microfibrils can withstand drying without distortion. But if you do remove hemicellulose, the drying alone is enough to crush the cellulose framework, so that the D.P. upon hydrolysis drops down to low levels (see further, *Fundamental Aspects of Papermaking Fibers*, Chapter 4, British Paper and Board-Makers Association, Kenley, Surrey, England, 1958).

Crystalline cellulose is protected from acid hydrolysis because it has an orderly array of hydrogen bonds between the cellulose chains. As long as you have an orderly array of hydrogen bonds, water cannot break the hydrogen bonds, and acid cannot break them either before you come to concentrations high enough to cause swelling, i.e., far beyond the limit you use in sulfite cooking. If you do bend the fibers beyond the elastic limits, a few hydrogen bonds will be opened and reformed in a disordered way, which is enough to make it possible for the acid to hydrolyze the acetal bonds and break the chains.

In this respect, a very appropriate name for this effect is to call it "latent damage," as proposed by Dr. Stone. I don't think it is possible to dicover such damage without applying hydrolysis. We have seen now that the more acidic the medium is in the pulping process, the more pronounced is the effect of such chip latent damage in the process.

In the neutral sulfite and kraft processes, we have very little effect of chip damage. In the kraft process we know that the cellulose and hemicellulose is not degraded by hydrolysis. The polysaccharide chains are degraded by an "unzipping" reaction from the chain ends. Such a decomposition would not be related to the hydrogen bonds because it does not require the separation of chains.

I think that residual stresses which we may have in the distorted fibers of damaged chips are of little importance in comparison with the hydrogen bonds, or rather the regularity of the order of the hydrogen bonds. By simply assuming that we disorder these bonds by bending the fibers beyond the elastic limit we have actually a mechanism which could explain the differences in behavior of the damaged chips to different cooking liquors of increasing acidity from the alkaline over to the acid side.

I think this proposed mechanism is in conformity with all the data we have heard this morning. The experimental material presented is extremely interesting, and I think we can learn more by applying a principle like the one outlined here.

CHAIRMAN CHILSON: Thank you very much. The discussion seems to point toward the protection of the alpha cellulose. I was wondering if Dr. Nolan might have a remark or two in connection with this most interesting subject.

W. J. NOLAN: I am very much in agreement with the previous speaker, on cellulose particularly. What is the best way to protect the cellulose during cooking? That is the primary question.

Some people plan on obtaining this protection through preimpregnation while others will depend on natural penetration during the early stages of the cook. We at Florida are depending on the exclusion of penetration.

If you plan on impregnating either before or early in the cook, what is being accomplished? You are absolutely placing the cooking chemical in direct contact with the cellulose, not with the lignin. (The chemical must diffuse from the fiber lumens, through the cell wall to begin reacting with lignin). I don't care whether this impregnation occurs in 5 min., 50 min. or 10 hr.; as soon as the impregnation is complete, the cooking liquor, being in contact with the cellulose, will react with that cellulose. This we are against, on general principles, and is our theoretical starting point at Florida.

What we have tried to do was find some way to avoid this preimpregnation, impregnation, or other devices which bring the liquor in contact with the cellulose. We want to avoid, as far as possible, such practices in order to protect the cellulose. That is one of our primary aims.

Every available cooking chemical will degrade cellulose as it reacts with lignin. Let us then find a mechanism—whether

it be the true, partially true, or even erroneous explanation—whereby we can reach and dissolve the lignin, leaving the cellulose with minimum degradation.

My opinion is that the best way to do this is to keep the cooking chemical away from the cellulose as long as possible. In other words, avoid deliberate impregnation in any form.

We have been cooking in the laboratory for many years and we have not had impregnation. You in the sulfite mills are faced with it in every digester charge. You have impregnation, due to the temperature rise schedule, and it can be avoided, but perhaps not with existing digesters.

What I am trying to say is make a break with tradition. Many of you have been faced with impregnation throughout your pulping experience. The effects of the pulping variable, even the role played by the wood itself, became colored in terms of impregnation. I maintain that you don't have to have this impregnation. If you can put your wood into such a condition that you can work from the outside toward the center and avoid the early soaking of the chip with chemical, then you can prevent a high percentage of destruction or degradation of cellulose.

This mechanical treatment of chips seems quite simple to me, having done it for several years, but perhaps I am oversimplifying. It sounds awfully easy, saying that all you have to do is find mechanical means to change the shape of your chips. (We have found that it is actually easy if attrition mill are used, somewhat more difficult with hammer mills, to bring about small cross sections across the grain.)

Of course, all this involves a little bit of mental change too. We have to stop doing things the way grandfather did, just for tradition's sake. He had to use chips, we are still using chips, but we don't have to use the same size and shape he used.

I don't care whether you use attrition mills, hammer mills, or what-have-you—get the wood in such shape that you can work on the lignin and not on the cellulose.

Chairman Chilson: Thank you very much, Doctor. I see we have a design on the blackboard over here. Let us hear the explanation.

Dr. Rånby: What I have drawn here is just a few formulas to explain the point which I should like to bring out.

First of all, we must remember that in all cellulose materials in the dry state, all hydroxyl groups, so far as we can determine from infrared absorption spectra, are engaged in hydrogen bonds. I have drawn one hydrogen bond (Fig. 1) to show what it looks like.

One oxygen (left) can be either in an acetal group or in a hydroxyl group. The other part of the bond (right) must

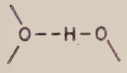

Fig. 1

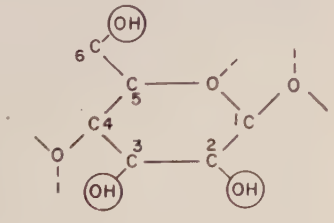

Fig. 2

always be a hydrogen donor, i.e., in this case a hydroxyl group. All three hydroxyl groups in cellulose, on the sixth, second and third carbon atoms, respectively, are engaged in hydrogen bonds of this type (Fig. 2). So far as we now know, all oxygens in the glucose rings and between the rings in the cellulose chains are hydrogen bonded as hydrogen acceptors due to their extra electron pair which is not engaged in any other bonding. These assumptions are based on infrared and x-ray evidence.

We now schematically look at the cellulose fibril. It is largely crystalline, or at least well ordered, and in the lattice

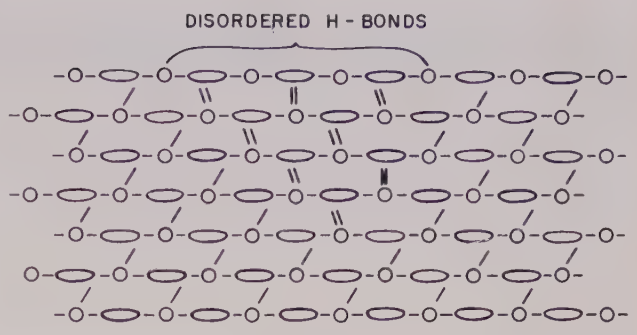

Fig. 3

we have hydrogen bonding between the chains in a regular way, as schematically shown in the drawing (Fig. 3). We have assumed that all acetal oxygens are hydrogen bonded with hydroxyl groups in adjacent chains. In crystalline cellulose the hydroxyl groups on the third carbon atom are assumed to be engaged in intrachain hydrogen bonds to the ring oxygen in the adjacent glucose units.

For the hydrolysis we need protonation of the oxygen in the glycosidic links, i.e., the oxygen group between the glucose units. Furthermore, to break the chain, of course, we have to move at least one glucose unit out of place, which would require breaking of several hydrogen bonds.

We can see now what difficulties will be involved in hydrolysis of crystalline cellulose with its complete set of hydrogen bonds inside the lattice: the protons can't penetrate, water cannot penetrate, and the breaking of the glycosidic bond requires opening of several hydrogen bonds. Only by a simultaneous breaking of this glycosidic bond and a set of hydrogen bonds can we break a chain in the lattice.

But if we have distorted the lattice by bending, the hydrogen bonds become disordered Fig. 3). This makes it possible for protons and water to penetrate the lattice by opening the hydrogen bonds. It then becomes much easier for the hydrolytic reaction to open one glycosidic bond to break the chain, or to remove a glucose unit by opening two adjacent bonds in a chain.

The chip damage can be so severe that fibers are ruptured. We can also have permanent deformation, where the whole fibrillar system is distorted along planes across the fibers in the wood. In such case, it is very likely that the hydrolytic attack on the wood chips will break the fibers into shorter pieces just from the simple mechanism outlined here.

I think you could predict that thin chips would be more difficult to damage than thick ones just because a thin chip is expected to have a higher elasticity limit in deformation. That would be speaking in favor of the Norman Chipper. I should like to know if this prediction is in agreement with the experiments, i.e., that you do get less chip damage there.

Chairman Chilson: Thank you, Dr. Rånby. We have been talking about wood damage.

If I remember correctly, in Dr. Stone's written paper or in one of the papers, he has presented us with a rapid method for determining the amount of damaged wood in a chip. I am wondering if that would be worth while presenting to us at this particular time. Do you want to do that, Dr. Stone?

J. E. Stone: We don't have a rapid method for measuring the amount of damage in wood. It is something which is needed by the people in mills, by chipper manufacturers, and by many others.

At the Pulp and Paper Institute of Canada, Dr. Yorston is attempting to work out a simple and rapid method. One method involves a rapid hydrolysis of the chip with mineral acid, followed by abrasion with an airblast. The degraded material can be separated from the material which is undegraded, and the amount of each is measured.

Another method consists of taking a supply of chips, hydrolyze with mineral acid, stir with water for a given time, and weigh the amount of material which resists disintegration.

There are also staining techniques using the preferential adsorption of dyes in those areas which have been disrupted, but I would say that at the moment there isn't a really satisfactory method, and it is still something that we need.

CHAIRMAN CHILSON: . . . I believe one method was described in Green and Yorston's paper.

DR. STONE: One was described by Yorston in 1939 and 1940, but he is still working on it. He now uses other acids than sulfur dioxide, the latest being a mixture of methyl cellosolve and para-toluene sulfonic acid. The wood is cooked in this reagent, the chips broken up in a British disintegrator, a 1-g. aliquot taken and stirred in a measuring cylinder. The suspension is allowed to settle for 20 min. and the volume of sediment measured. The greater the damage, the smaller the volume.

CHAIRMAN CHILSON: . . . Dr. Nolan, I believe, has a question or two that he would like to ask or a statement he would like to make in connection with Dr. Rånby's last comment.

DR. NOLAN: It includes both of these last statements. I don't know how we can evaluate real cellulose in wood or pulp. Right now the chemistry of cellulose, and particularly of lignin, is far from being well-defined. With the wood components, we are working in an almost empirical field; so let us stick to empirical methods for evaluating our immediate problems in pulping.

I prefer a more direct approach to our pulping problem rather than the fundamental chemical approach which investigates the individual chemical reactions involved in pulping, the chemical bonding between fibers in the sheet, etc. (Eventually, I am sure, this approach will be of extreme value when we can produce cellulose in its original form and free from lignin.) We are faced with the heterogeneous mixture of chemicals in wood as nature gove it to us. We have found that chips are the best physical form thus far available for bringing about a chemical separation of the wood components. The digester, with all its vageries of temperature, liquor distribution, etc., is the best possible vessel yet found to bring about this separation and we are stuck with it until new designs are available.

We can do a great deal on the physical side of processing through changes in methods of chipping and related mechanical processing. We cannot do anything about the chemical reactions themselves since they follow natural laws. We are all so-called experts but we know surprisingly little about what specifically takes place chemically in the digester. Let us attack the problem from a practical, common sense point of view, using necessarily empirical methods to explain the physical chemistry involved.

What I am suggesting is that we forget the traditional explanations of the process we were given when we "broke in" or which we read in the old textbooks. Let us look at the physical structure of wood, the chemicals we have available to work with and let us forget, temporarily, the tremendous field of organic chemistry that is involved. The true explanation of the organic chemistry involved will come sooner or later but I doubt that such knowledge will be available in your technical lifetime or in mine.

I suggest the empirical approach as a means of obtaining immediate improvements in carrying out the chemical reactions. Let us try opening up the surface of the wood and find whether it speeds up or slows down the overall delignification rate and whether it improves or reduces the quality of the cellulose. Does impregnation protect or damage cellulose, can impregnation be avoided in the digester or will we be always faced with it?

Yesterday I presented some information showing that we pulp rapidly and that it can be done without damage to the cellulose. Such procedures are not practical with the present sulfite digesters, but must we continue to use digesters of the same design? I am talking about what will be the practices in the next ten or fifteen years and how we can best influence such practices.

Let us look at what is happening on the surface of the chip as the cook starts. If we look too closely into the fundamental chemistry of the reactions involved, I am afraid the answers will be a long time in coming. What I would like to find is an empirical explanation of the pulping variables whereby the minimum cellulose degradation takes place. At this point I don't care whether we have the fundamental explanation or not.

CHAIRMAN CHILSON: Thank you very much, Dr. Nolan. Are there other questions from the floor?

MR. WARDWELL: I just wanted to make a statement about Dr. Gallay's speaking about the thin chips. It just happens that the Norman chipper makes chips much thinner than the standard chipper. We don't quite understand why it is, but it is a step in that direction.

There is one other thing I would like to ask Dr. Stone. He spoke about splitting action, and I want to clarify my understanding that this splitting action reduces the damage across the grain. Is that right?

DR. STONE: No, all I really could say about the splitting action is that it is commonly believed that chips are formed by a shearing action. We find that with knife angles of 30° or less it is not a shearing action. The chip is formed by splitting. It seems likely that the amount of damage is affected by whether splitting or shearing is involved in separating the chip from the parent log, but we have no data to show which action is the more detrimental.

I was watching the movies of the Norman chipper, and it looked to me as though there was, in this case, splitting rather than shearing. It was going a bit too fast to really see.

MR. WARDWELL: I wanted to say that in the Norman chipper when we first started out, we tried to make a 35° angle, and we never got to 30. We couldn't make the knives stand up even at 35°. We have gone back to 38°. The old standard chipper was 45°.

DR. GALLAY: I have just a brief word in addition to what I said earlier. I agree with what Dr. Rånby said in general. I should have used the term carbohydrate in place of cellulose since I wished to include hemicelluloses, but I did not want to go into the intimate details of an intrafiber mechanism of degradation.

In addition, the following might be noted. Dr. Stone has shown in the past that a compression as low as 5% parallel to the fibers will produce appreciable damage. It is difficult to conceive of the buckling of a pristine undried tracheid, reasonably elastic in nature, without the action of some hydrolytic or similar factor which will change the stress-strain characteristics of the fiber in the direction of less toughness or more brittleness. This may be a matter of putting the horse before the cart rather than otherwise.

In short, I am suggesting that the emphasis should be placed on the degradation effect of the acid.

DR. STONE: Actually Dr. Gallay raised this question in Montreal, and I have been wanting to answer it ever since.

I think Dr. Gallay has been saying that the buckling of the fibers may crack the lignin layer around the fibers and permit easier ingress of acid, which will hydrolyze the cellulose.

I certainly think there are cracks, but it depends on what scale one is talking of in terms of cracks. The ones Dr. Rånby is talking about are at the molecular level. These are really the ones which cause the harm. The acid has a greater accessibility to the cellulose molecules and chops them off.

As far as putting the cart before the horse is concerned, the buckling due to compression comes before the acid hydrolysis, that is, when the chipper compresses the wood. The hydrolysis comes afterwards. If the buckling wasn't there, you wouln't get the hydrolysis.

DR. RÅNBY: I think you could predict that the thin chip

would be much more difficult to damage than the thick one because just the elasticity goes further if you have a very thin one. That would be speaking in favor of the Norman chipper. I would like to know if that is in agreement with the experiments, that you do get less chip damage there.

Mr. Wardwell: I think Dr. Tomlinson of Howard Smith has gone now. That point is included in the written paper about some experiments that his organization carried out with magnefite pulp. He said in comparison with ordinary sulfite pulping that the magnefite pulp from the standard chipper was weaker in tear, but when chips from a Norman chipper were used the magnefite pulp had a higher tear. Also, that a still further improvement in tear was obtained with chips made with a laboratory chipper. That is, there is still less damage in the laboratory chips.

Dr. Nolan: These discussions on chip damage, both here and in the literature, seem to me to exaggerate the actual damage that can be done in a well-operated chipper. Let us consider the length of a chip; it is five to seven-eights of an inch long. The fibers we are supposed to be damaging so severely are less than 3 mm. long. Since we have to put the whole mass of fibers through the chipper, we blame everything that happens to the wood and fibers, both from mechanical treatment and chemical treatment in the digester, on the chipper.

On an average, what percentage of fibers can be damaged in the chipper? It is far less than 10%. These so-called bruised fibers are not destroyed, they are probably only slightly inferior for papermaking purposes. I don't care whether you use a Norman chipper or some other chipper. From a standpoint of fiber damage due to crushing, I don't think any chipper does much fiber damage; by far the greatest fiber damage occurs in the digester. The true test of chipper performance in the amount of sawdust and fines produced.

In the digester, we have two principal wood compounds in contact with the cooking chemicals. One compound, the lignin, we try to destroy; the other, the cellulose, we try to conserve. The damage that can be done to the fiber, or cellulose, in the digester is far greater than any chipper can do. Therefore, I think our main concern should be with what happens in the digester. The differences in fiber quality brought about by differences in cooking procedure are far greater than the differences created by differences in chipper operation.

Let us take a good sound look at the facts and learn to evaluate what is happening in the digester. Once we know this we can adjust our mechanical treatment of the wood to best fit the requirements of the digester.

Chairman Chilson: I noticed that both Dr. Stone and Dr. Sanyer showed in their slides the terrific effect on the folding endurance test. Dr. Stone showed that the fold was practically zero if the compression was carried to a certain degree and Dr. Sanyer also showed that the fold was very low for the sawcut chips.

I was wondering if any member of this distinguished panel could help me out and give me an explanation for this. In the processing of hardwood kraft pulp the folding endurance continues to rise during the beating when we must be producing a substantial quantity of fine material. With chip damage, we must be producing some short material too, but that doesn't seem to contribute to the folding endurance even after extensive beating. Can anyone answer this apparent contradiction?

Dr. Gallay: The fold endurance property of paper is very complicated involving a number of basic characteristics of the fibers and the sheet as factors. It is well known that the course of folding strength with beating is an increase to a maximum followed by a decrease before the corresponding tensile or bursting strength begin to level off.

From the theoretical point of view, it has been suggested by Rance in Britain that the fold endurance strength is related to the Hookean portion of the stress-strain curve. He obtained an empirical relation between these values. Based on this, we would have to say that the damage under discussion is due to a marked reduction in the ability of the fibers and the fiber network to take up a stress and show recoverable strain. The structure now seems to show a considerably increased degree of plasticity and less elasticity. Whether this is due to more readily broken bonds or to the fibers themselves is a matter of conjecture.

Chairman Chilson: Dr. Stone, do you have anything in connection with that?

Dr. Stone: No, I don't think I do. We are currently looking at failures in paper caused by folding, tearing, etc., using the scanning electron microscope, and it seems that much may be learned from observations of this sort. If we know the reason why the material fails, perhaps we can do something about it.

I would say that the pulps from damaged wood have very low stretch, and this is related to what Dr. Gallay is saying.

Mr. Carlish: I would like to make a comment in regard to some remarks Dr. Gallay made in relation to folding behavior of fibers. That refers to the behavior of compression damage of fibers in the beating operation. There may be a certain relationship there because if you beat compression damaged fibers, a peculiar phenomenon occurs. You do get fragmentation of the fiber without any adequate fibrillization. As a result a low order is obtained, and the pulp and paper produced has not a chance to develop strength. I just wondered if Dr. Gallay may concede that there is various behavior in relation to folds. Here in beating there is a certain amount of folding involved and flexing. You may get an effect which is perhaps related to Dr. Rånby's remarks, that if splits in the microfibrillar structure, then you get a local degradation. If a low D.P. of cellulose is obtained, you get at the same time relatively high brittleness. The fiber gets very brittle, and it cannot be subjected to any mechanical action.

Dr. Gallay: I agree fully with that statement. The chief phenomenological effect of the lowering of the D.P. is embrittlement of the fiber, and Dr. Rånby has gone into detail with regard to the changes which occur. I mentioned this factor a few minutes ago.

The ability of the paper structure to absorb stresses, particularly those involving flexure as exemplified by fold is drastically reduced. The toughness of the fibers and the network structure is impaired.

Dr. Sanyer: We have been trying to get some idea from measurements on sheets about the strength of fibers. From all these discussions it is apparent that the strength of the fiber decreases or the number of weak points per fiber or weaker spots in the fibers increases as the acid susceptibility of the wood increases. For this purpose, the strength measurement with individual fibers is difficult.

What we are attempting to do is to make debonded or partially bonded sheets and measure the tensile strength within a span of the fiber length, which is about 3 mm. in case of sawcut chips. The strength of the fiber goes down as the span is increased from zero to 1 mm., and after that it remains constant. It shows that the segment length is not much more than 1 mm. With the normal chip this value is about 2 mm.

[Slide] This area gives us an idea of the fiber strength, but we still didn't succeed in making internally bonded sheets. That is, the fibers have to be dried under tension from water and then made into an unbonded sheet and compared with the bonded sheet. However, the bonded sheet strength is quite a bit higher than this level shows. We are attempting to get the distribution of the segment length or of the strength and the number of weak spots per fiber.

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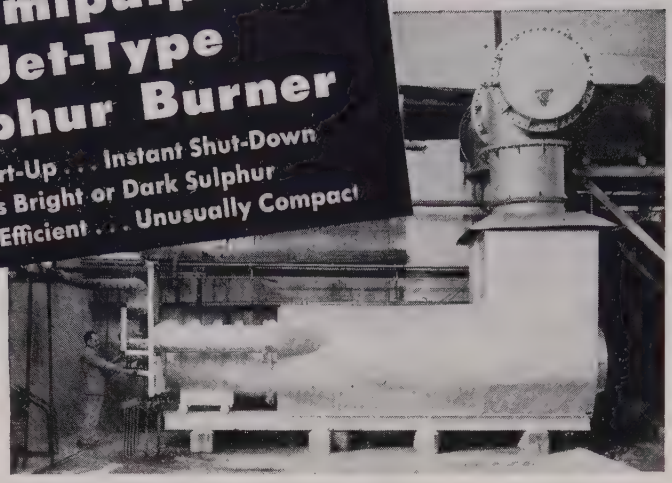

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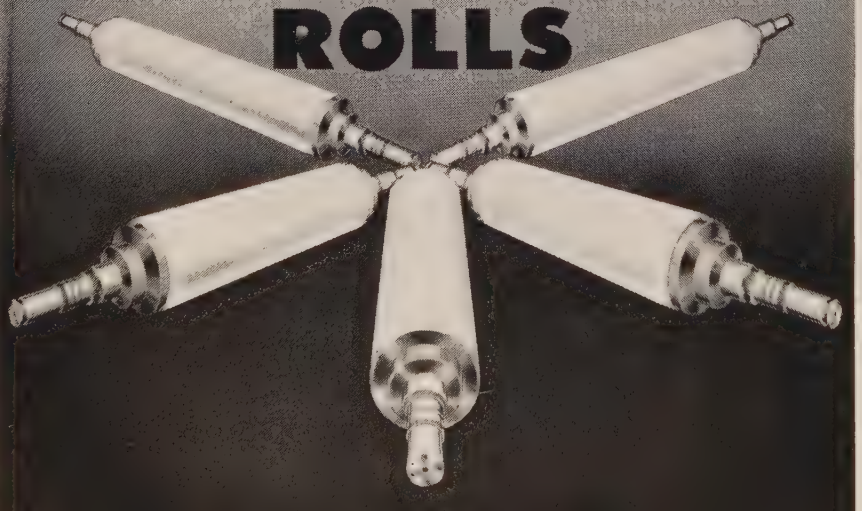

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is a direct indication that there is a loss in fiber strength.

DR. GALLAY: I cannot resist the temptation to say something generally about physical testing. The tests we use are all empirical and arbitrary and the results will vary with the test instrument and the variables associated with the test. The tensile test, probably the simplest, depends on the length of sheet span under test and rate of loading. The burst test depends on the diameter of the orifice and the rate of loading. The fold test depends on the amount of tensile stress put on the paper during the test. As a matter of fact, using the two common testers for this property, viz. MIT and Schopper, you can frequently obtain instances where the order of value will be changed or even reversed. Thus, one must be very careful in judging the merit of paper by our test methods, particularly in relation to actual use requirements. Unfortunately the relationships between these physical tests and basic characteristics of the sheet are not at all well known.

DR. NOLAN: You are discussing the physical material as it comes to your hands. What is the past history of that material before you received it. You can rather accurately evaluate the strength of that material in tensile, burst, tear, etc., but what is the material you are working on. No two mills in the United States and Canada and no two laboratories cook in exactly the same way. If we have three samples of exactly the same pulp I am sure that you, Dr. Gallay, and I will come up with very similar physical evaluations of that pulp. With three different pulps, three different physical evaluations will result.

What I am trying to say is that the variations in pulps are much greater than pulp analyses show. Cellulose and lignin content, D.P. number, etc., are all average figures. The range of lignin content of the fibers or D.P. number of the cellulose in the fibers can be extremely wide in a single pulp sample. The magnitude of those ranges will vary with the method of cooking.

I believe that our physical testing methods are far more accurate than our cooking methods. Let us find out how best to cook and to do it uniformly; our physical testing methods will be able to evaluate these "ideal pulps."

CHAIRMAN CHILSON: Gentlemen, there still are apparently a lot of unanswered questions. I would like to take this opportunity to thank everybody for their kind attention. I would especially like to thank the speakers for their presentations and also the panel who have so graciously entered into this discussion and made this meeting so worth while.

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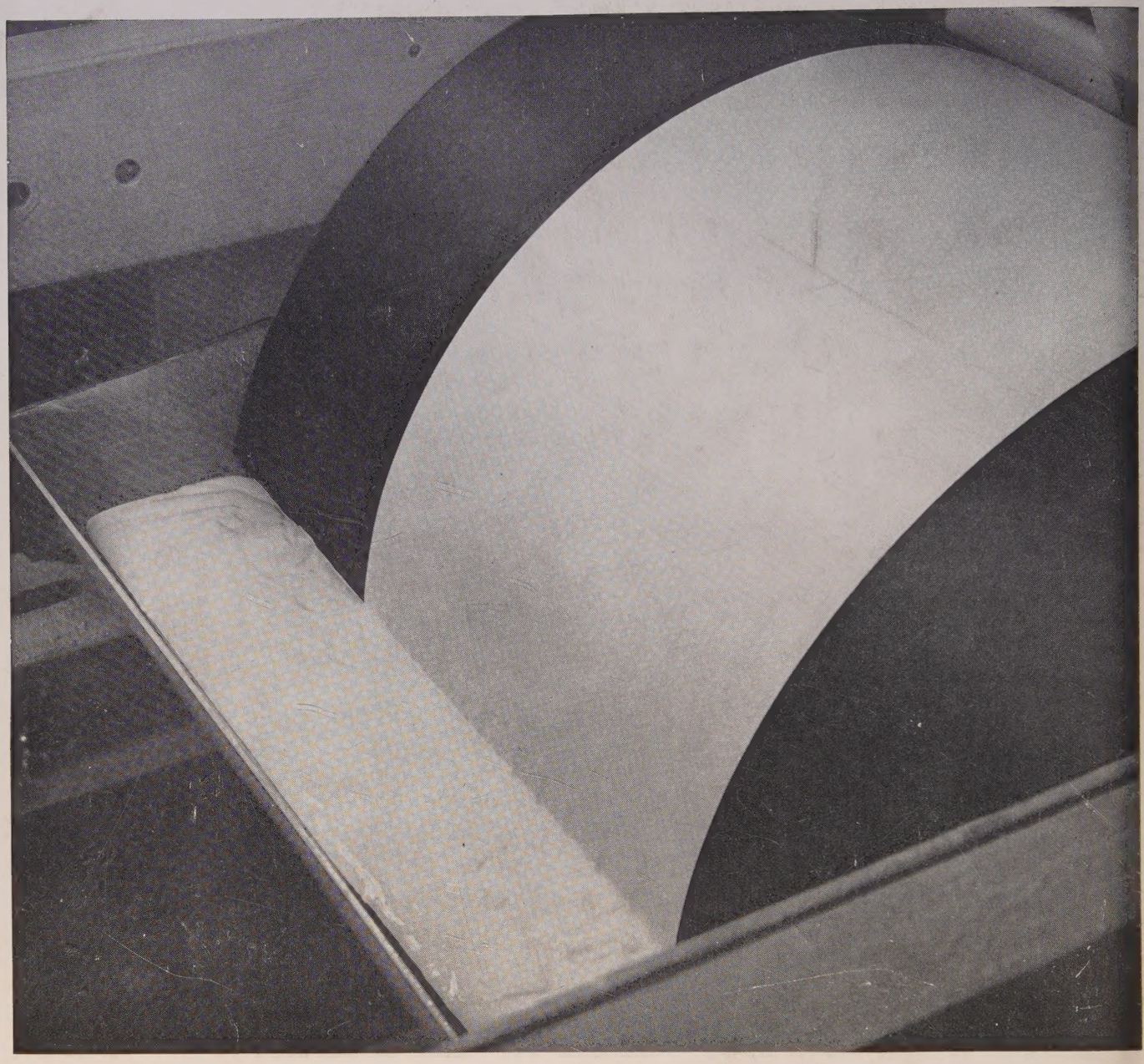

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